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STUDY OF AIR POLLUTION ASPECTS OF VARIOUS ROADWAY CONFIGURATIONS

SEPTEMBER 1, 1971

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FINAL REPORT

ON

STUDY OF AIR POLLUTION ASPECTS

OF

VARIOUS ROADWAY CONFIGURATIONS

SEPTEMBER 1, 1971

Submitted To

New York City Department of Air Resources

By The

General Electric Company
3198 Chestnut Street
Philadelphia, Pennsylvania 19101

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1. Introduction

1.1 Study Objectives

The increasing cost of real estate, demand for better vehicular transportation and number of registered vehicles in urban areas suggest that the urban dweller will live close to major arterial highways and will be subjected to high doses of pollutants such as carbon monoxide, particulate matter, oxidants, and oxides of nitrogen. The advent of the Clean Air Act of 1970 projects relief in the year 1975. Achievement of these clean air goals, however, is dependent upon knowledge and use of that knowledge, of the relationship of vehicular generated air pollution and the configuration of urban roadways. Therefore, it is necessary to:

1. Assess the potential effect of alternate roadway configurations on ambient air pollutant concentrations in and about such roadways, surrounding working and living areas and to relate indoor and outdoor concentrations.

2. Develop generalized guidelines for use by urban and transportation planners to guide the future design of urban expressways to results that are consistent with national and local air quality standards and objectives.

This experimental study was undertaken therefore to:

1. Ascertain the current air quality in the immediate vicinity of various urban roadway configurations.

2. Determine how the selected urban roadway configurations aid or hinder the diffusion of the pollutants emitted by urban traffic.

3. Develop mathematical relationships between traffic, traffic speed, pollutant concentration, meteorological parameters and roadway configuration.

The study has shown that it is possible to assess the impact of the 1970 Clean Air Act by future monitoring programs which determine the extent to which the clean air goals are achieved. It is possible to identify those areas in and around a given configuration that do not meet the National Air Quality Standards under certain meteorological and traffic conditions. With this information, it might be possible to modify traffic flow rates and speed such that, for a given roadway configuration and meteorological situation, the National Air Quality Standards will be met. Similarly, it is possible for urban and transportation planners to compute in advance the pollution anticipated for a proposed roadway design in order to insure that dwellings adjacent to the proposed design will not be exposed to pollutant concentrations in excess of the National Air Quality Standards.

The quantity and the quality of the data taken as well as the models developed for the wide range of urban configurations evaluated, in one of the most complex urban communities, namely New York City, lead toward a better understanding of the diffusion of pollutants and meeting the study objectives.

1.2 Study Participants

This study was conducted under the leadership and guidance of the New York City Department of Air Resources. The field work and data analysis was performed by the General Electric Company. Five other city, state and federal agencies participated in the study.

The Department of Transportation, New York City, provided services for site selection, site use permits, equipment set up and detector installations and site security.

The Department of Transportation, New York State, using its own personnel and equipment, conducted traffic data collection on a 24 hour basis throughout the field phase of the study.

The Department of Health, New York State, provided technical assistance by use of its own staff to the New York City Department of Air Resources.

The Air Pollution Control Office, E.P.A. (formerly National Air Pollution Control Administration, H.E.W.) provided funding of the air pollution monitoring, data analysis and report writing phases of the study through a contract with the New York City Department of Air Resources.

The United States Bureau of Public Roads, New York Division Office, provided on a matching fund basis, support of the traffic data collection activities of the New York State Department of Transportation.

1.3 Roadway Configurations Evaluated

Ten urban roadway configurations were evaluated. These configurations and their location are tabulated below in the study sequence:

Roadway Configuration	Location
Covered on Top-Open at Side	Franklin D. Roosevelt Drive at Sutton Place
Long Tunnel (ventilated)	Brooklyn Battery Tunnel
Shallow Cut	Brooklyn Queens Expressway at Hicks St.
Short Tunnel (unventilated)	Cross Bronx Expressway at Hugh J. Grant Circle
Deep Cut	Cross Bronx Expressway at Nelson & Jessup Avenues
Grade Road	Bruckner Expressway near White Plains Road
Cantilever Cover	Grand Central Parkway at Parsons Blvd.

Roadway Configuration	Location
Viaduct	Brooklyn Queens Expressway at Park and Navy Streets
City Street	Canal Street between Church and Mercer Streets
Intermittent Span	Trans-Manhattan Expressway at George Washington Bridge Plaza

These sites were chosen because they represent typical roadway configurations one would expect in any urban area. They range from simple grade configurations to complex city streets. The city street was chosen to show levels existing on one of the more heavily travelled streets in New York City, and was the major lower Trans-Manhattan artery between the Holland Tunnel and Brooklyn.

The ventilation characteristics for the sites ranged from good (open configurations, such as the Viaduct site which was surrounded by a large park and apartment/school courtyard) to poor (closed configurations, such as tunnels).

The peak traffic flow rates for the configurations studied ranged from 12,000 vehicles/hour to 1,500 vehicles/hour, thereby encompassing a wide spectrum of the traffic flow rates that would be encountered in any urban area.

1.4 Study Report

This report describes the study, its results and how they apply to meeting the above objectives. For purposes of improving readability, this report is divided into seven volumes of which this is the first. Volumes 2 through 7 consist entirely of data. Volumes 2, 3 and 4 contain carbon monoxide data. Hydrocarbon data is in Volume 5. Volume 6 and 7 respectively, are Meteorological and Traffic data. It is hoped that this report will be of service in helping to meet the ultimate objective of cleaner air and still provide for better vehicular transportation.

2. Summary of Results

This section consists of five parts. The data characteristics are described in Section 2.1, traffic-air quality relationships are given in Section 2.2, site rankings by air pollution problem severity are given in Section 2.3, indoor-outdoor relations are given in Section 2.4 and recommendations for further work are given in Section 2.5. Each of the five sub-sections are further subdivided as noted at the beginning of the sub-section.

2.1 Data Characteristics - This sub-section contains brief site descriptions in 2.1.1, average diurnal traffic curves for each site in 2.1.2, horizontal and vertical carbon monoxide concentration distributions and isopleth plots in 2.1.3, meteorological patterns in 2.1.4, and hydrocarbon and particulate concentrations in 2.1.5 and 2.1.6.

2.1.1 Brief Site Descriptions - For purposes of summarizing results, it is convenient to classify the ten sites into the following five groups for reasons of similarity of geometric configuration.

A. Open Cut Sections - There were three of these as follows:

- A six lane deep cut on the Cross Bronx Expressway at Nelson and Jessup Avenue carrying 118,000 vehicles/weekday.
- A shallow cut on the Brooklyn Queens Expressway at Hicks Street carrying six lanes of traffic and 107,000 vehicles/day.
- A city street in Lower Manhattan at Canal Street carrying four lanes of traffic and 28,000 vehicles/weekday.

Sketches of the geometry of these three sites appear in figures 2.1-1A, B and C.

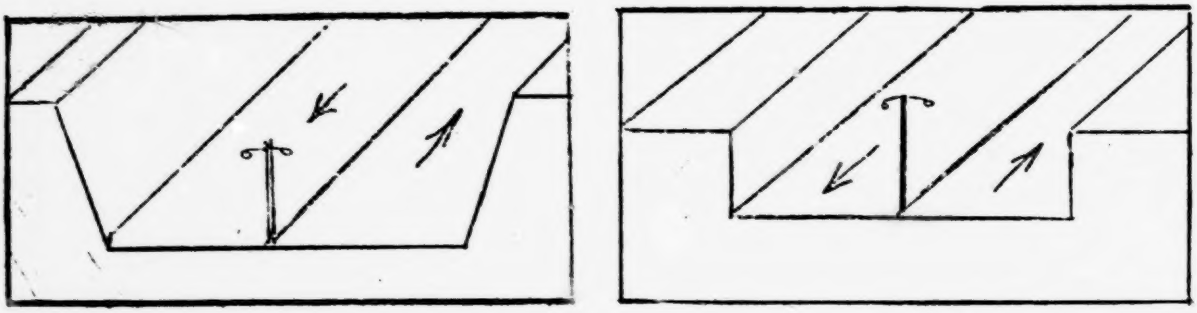


Fig. 2.1-1A

Deep cut section on Cross Bronx Expressway at Nelson & Jessup Ave. 6 lane road carrying 118,000 vehicles/day

Fig. 2.1-B

Shallow cut section on Brooklyn Queens Expressway at Hicks St. carries 107,000 vehicles/day.

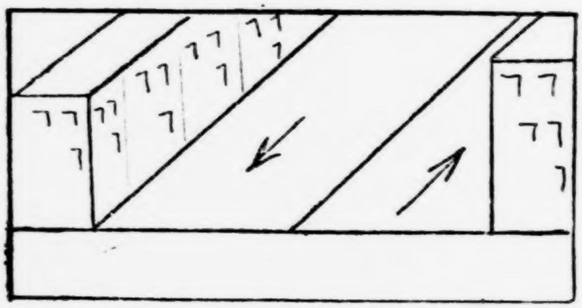


Fig. 2.1-1C

City Street - Canal Street in lower Manhattan carries 28,000 vehicles/day

Fig. 2.1-1 - OPEN CUT ROADWAY SITES

B. Tunnels - There were two of these as follows:

- The long, blower ventilated Brooklyn-Battery Tunnel
- A short tunnel without blower ventilation on the Cross Bronx Expressway at Hugh J. Grant Circle

Sketches of the geometry of these tunnels appear in figures 2.1-2A and B.

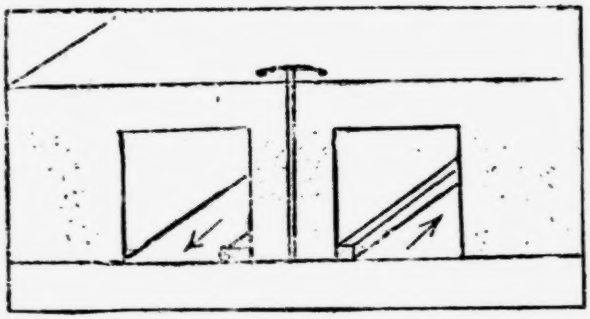


Fig. 2.1-2A

The long, blower ventilated Brooklyn-Battery Tunnel. 2 lanes eastbound carry 26,000 vehicles/day. 2 lanes west-carry 25,000 vehicles/day.

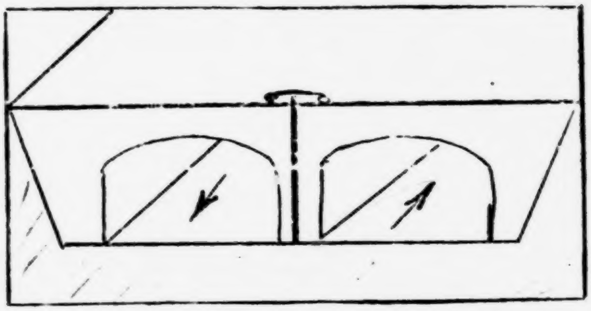


Fig. 2.1-2B

A short, unventilated tunnel on the Cross Bronx Expressway at Hugh Grant Circle. 3 lanes eastbound carry 44,000 vehicles/day. 3 lanes westbound carry 42,000 vehicles/day.

Fig. 2.1-2 - TUNNEL ROADWAY SITES

C. Cantilever Covered Roads - There were two of these as follows:

- A fully covered, open at one side configuration on the Franklin D. Roosevelt Drive at Sutton Place carrying six lanes of traffic and 97,000 cars per weekday.
- A doubly cantilevered, open in the top middle configuration on the Grand Central Parkway at Parsons Boulevard. The six lane road carries 110,000 cars /weekday. A pair of parallel service roads carry an additional 23,000 vehicles per weekday.

Sketches of the geometry of these two sites appear in figures 2.1-3A and B.

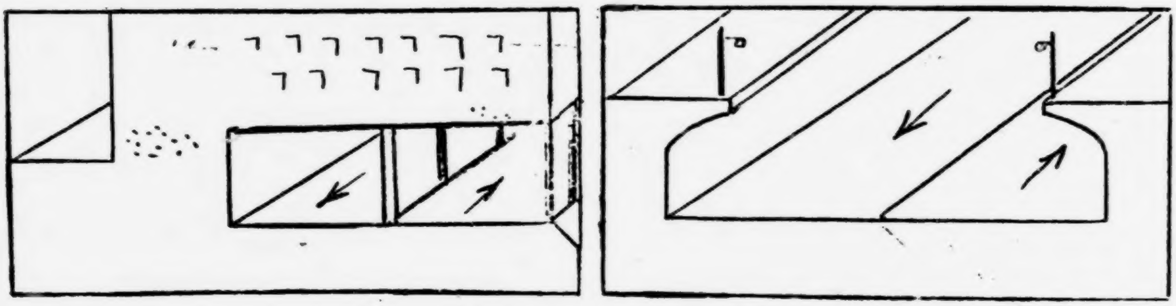


Fig. 2.1-3A

Six lane road carrying 97,000 cars/day. Fully covered open at one side, passing beneath an air rights building on Franklin D. Roosevelt Drive at Sutton Place.

Fig. 2.1-3B

Six lane road carrying 110,000 cars/day. Doubly cantilevered covering, open in the top-middle configuration on Grand Central Parkway at Parsons Boulevard. Parallel service roads carry 23,000 vehicles/day.

Fig. 2.1-3 - CANTILEVER COVERED ROADS

D. Open Configurations - There were two of these as follows:

- A grade road on Bruckner Expressway near White Plains Road and carrying six lanes of traffic. Traffic volume on highway and parallel service road averaged 55,000 vehicles/weekday.

- An elevated roadway on the Brooklyn Queens Expressway at Navy Street carrying six lanes of traffic.

Sketches of the geometry of these sites appear in figures 2.1-4A and B.

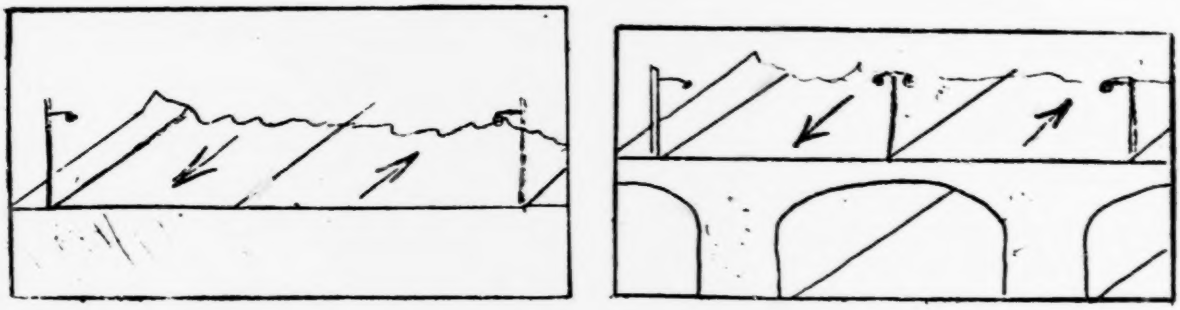


Fig. 2.1-4A

6 lane open roadway, with parallel service roads in each direction, on Bruckner Expressway near White Plains Road. Traffic volume averaged 55,000 vehicles/day.

Fig. 2.1-4B

6 lane viaduct roadway carrying 108,000 vehicles/day on Brooklyn Queens Expressway at Navy Street. Parallel service roads at grade carry an additional 11,500 vehicles/day.

Fig. 2.1-4 - OPEN ROADWAY CONFIGURATIONS

E. Intermittently Covered Roadway - These was one such site as follows:

- A twelve lane highway passing beneath a group of four air rights apartment buildings on the Trans-Manhattan Expressway. These buildings, known as the George Washington Bridge Apartments, straddle the highway as shown in figure 2.1-5. The Expressway carries 175,000 vehicles/weekday. Two parallel city streets carry an additional 15,000 vehicles/weekday.

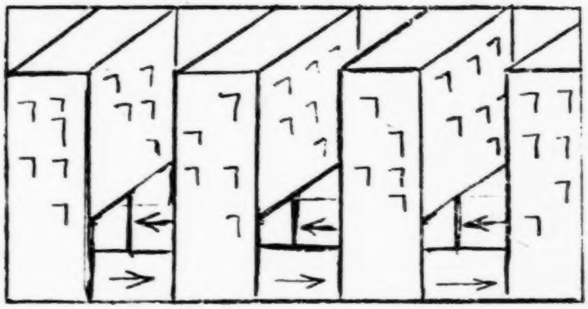


Fig. 2.1-5

Twelve lane highway passing beneath
a succession of four air rights buildings
on the Trans-Manhattan Expressway.
Road carries 175,000 vehicles/weekday.
Two parallel city streets carry an additional 15,000 vehicles/weekday.

Fig. 2.1-5 - INTERMITTENTLY COVERED ROADWAY

2.1.2 Average Weekday Diurnal Traffic Curves for Each Site

Figures 2.1-6 through 2.1-10 show the average weekday diurnal curves for traffic flow at each of the sites. For convenience of comparison the curves for sites having similar geometry appear on the same page. Thus the traffic curves for the three open cuts appear as figures 2.1-6A, 2.1-6B and 2.1-6C. Since traffic flow was bi-directional at all sites, a flow rate curve for each direction is given. Table 2.1.1 gives the hourly averages of truck traffic included in the diurnal traffic curves.

It will be noted from figures 2.1-6 through 2.1-10, that in general the traffic at all sites showed the two characteristic rush hour peaks, the slight dip between rush hours and the pronounced relative minimum between two and four A.M.

TABLE 2.1-1

TRUCK HOURLY AVERAGES

	Open Cuts			Tunnels		Open Sites		Cantilever Covered		Inter-mittently Covered
Time	Canal St.	BQE at Hicks St.	CBE at Nelson and Jessup Avenue	Brooklyn Battery	CBE at Hugh Grant Circle	Bruckner Expy.	BQE at Park & Navy St.	FDR Drive at Sutton Place	GCP at Parsons Blvd.	Trans-Manhattan Expy. At. G.W.B. Plaza
M-1	30		330		137	60	276	0	0	330
1-2	30	No	370	No	160	70	361	0	0	330
2-3	30	Data	420	Data	179	70	440	0	0	350
3-4	30	Taken	500	Taken	189	110	344	0	0	390
4-5	70		550		225	120	517	0	0	460
5-6	140		610		305	150	663	0	0	560
6-7	230		690		319	190	574	0	0	670
7-8	330		770		260	250	940	0	0	750
8-9	350		870		312	300	1039	0	0	870
9-10	350		850		317	350	939	0	0	930
10-11	310		880		299	360	850	0	0	860
11-N	290		930		324	350	999	0	0	920
N-1	270		830		319	340	951	0	0	890
1-2	280		750		285	360	921	0	0	870
2-3	310		900		317	330	1017	0	0	970
3-4	250		670		301	320	830	0	0	940
4-5	250		590		255	250	697	0	0	710
5-6	170		580		242	180	609	0	0	590
6-7	120		630		220	160	433	0	0	520
7-8	70		470		200	120	463	0	0	420
8-9	50		320		150	100	384	0	0	340
9-10	30		270		145	70	316	0	0	230
10-11	30		220		147	70	289	0	0	210
11-M	30		230		137	60	210	0	0	360

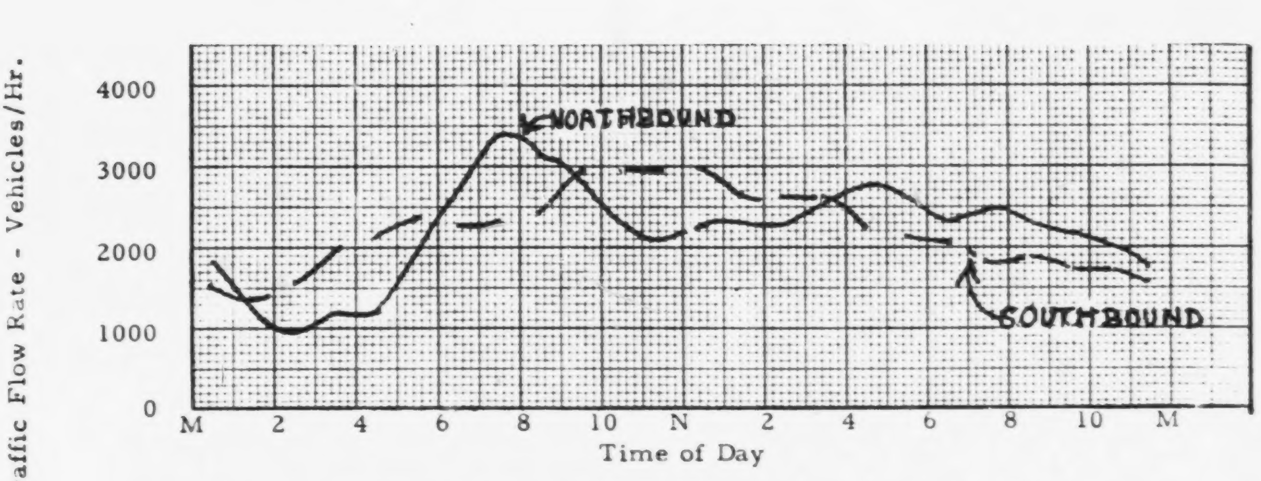


FIG. 2.1-6A Shallow Cut on Brooklyn-Queens Expressway at Hicks Street

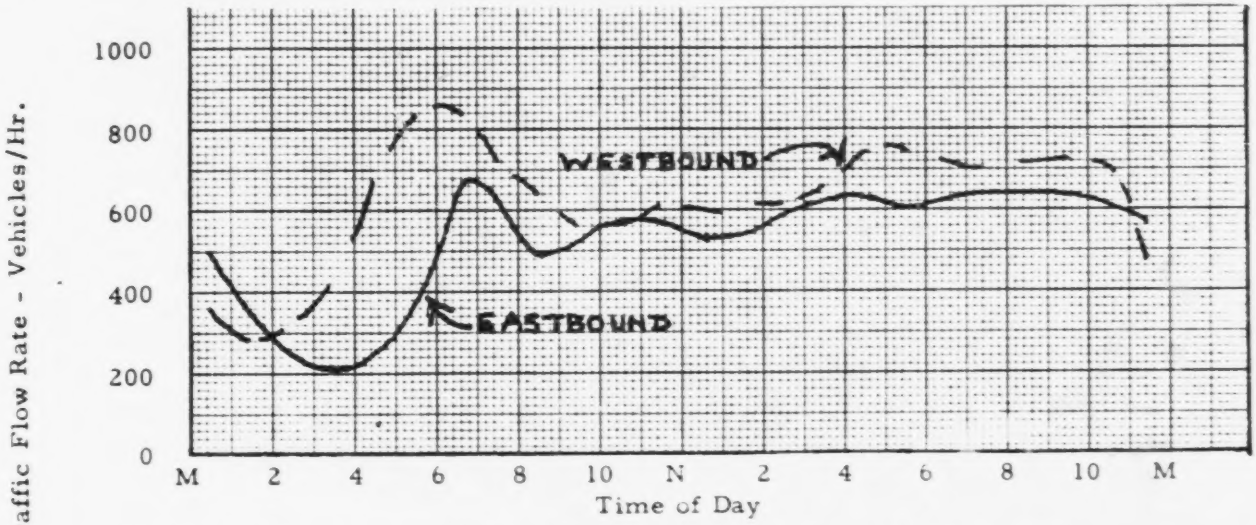


FIG. 2.1-6B City Street - Canal Street in Lower Manhattan

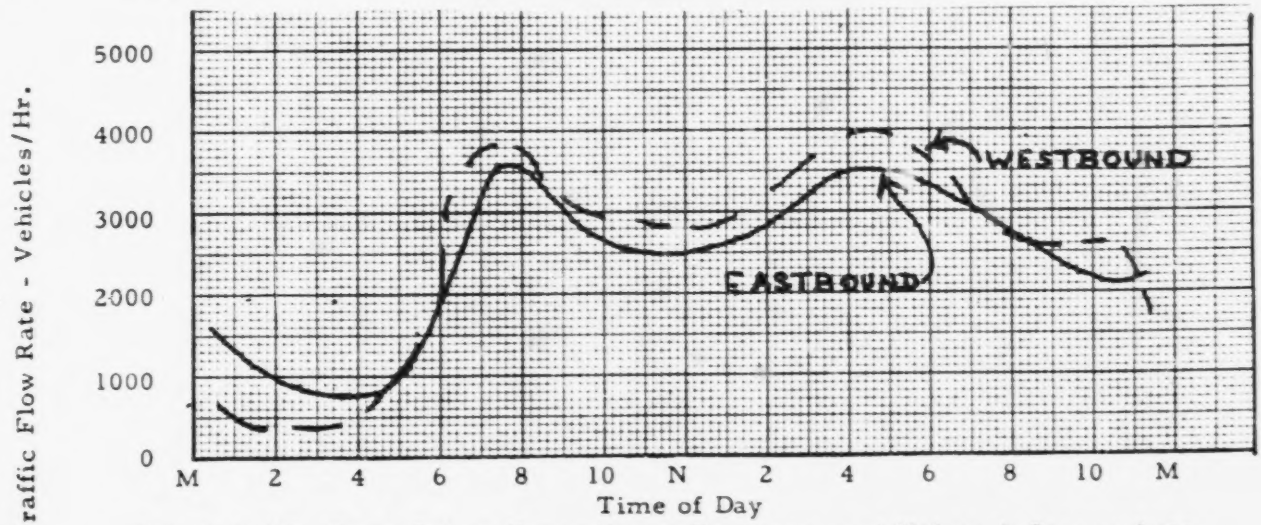


FIG. 2.1-6C Deep Cut on Cross Bronx Expressway at Nelson & Jessup Aves.

FIG. 2.1-6 AVERAGE WEEKDAY DIURNAL TRAFFIC FLOW RATES AT THREE OPEN CUT ROADWAYS

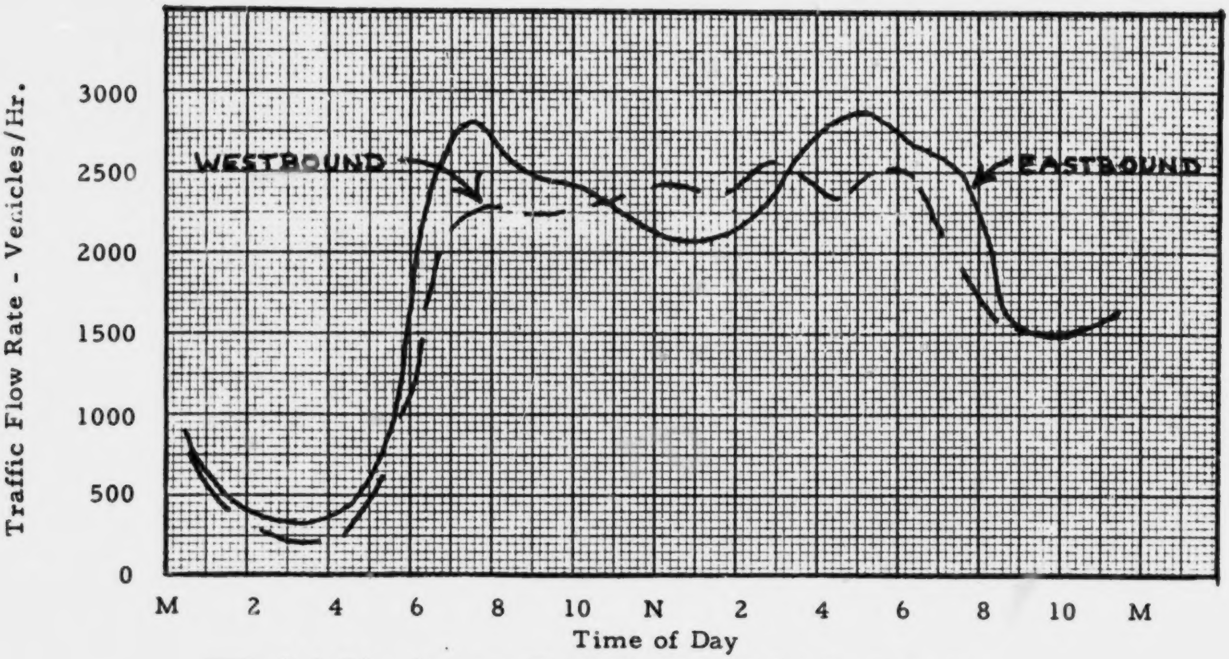


FIG. 2.1-7A Average Weekday Diurnal Traffic Flow Rate Characteristics in a Short Unventilated Tunnel - Cross Bronx Expressway at Hugh Grant Circle

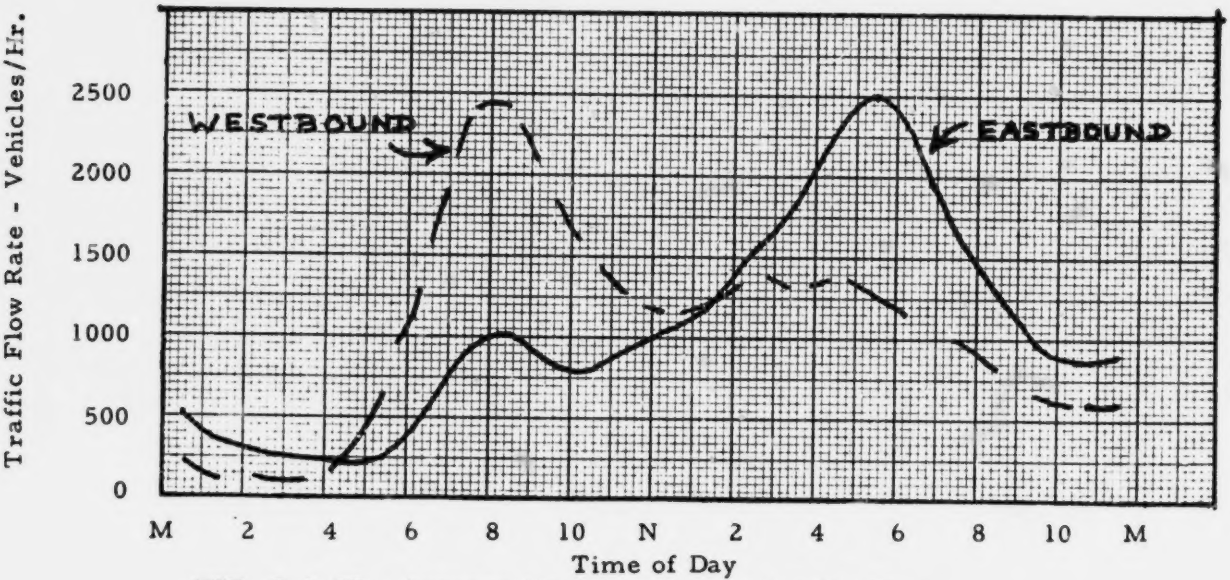


FIG. 2.1-7B Average Weekday Diurnal Traffic Flow Rate Characteristics in the Long, Blower Ventilated, Brooklyn Battery Tunnel

FIG. 2.1-7 DIURNAL TRAFFIC FLOW RATE CHARACTERISTICS IN TWO TUNNELS

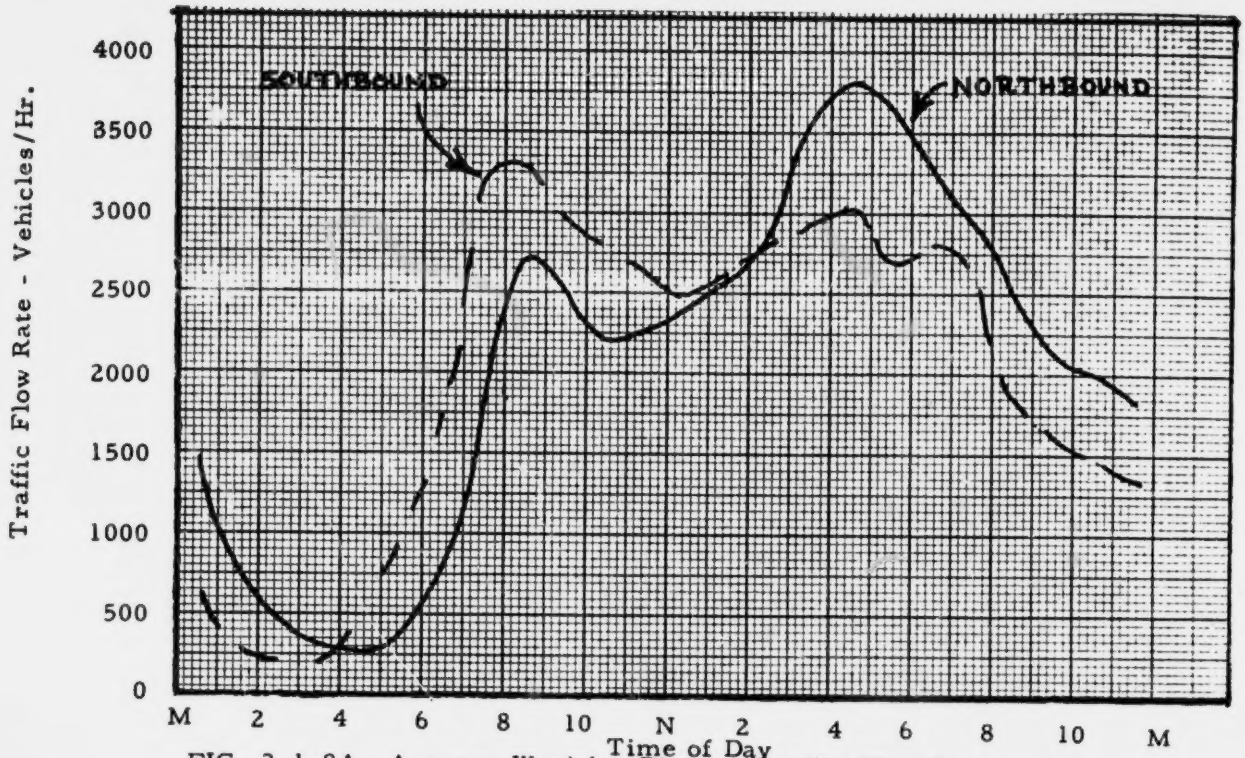


FIG. 2.1-8A Average Weekday Diurnal Traffic Flow Rate Characteristics on a Covered Roadway Open at One Side - Franklin D. Roosevelt Drive at Sutton Place

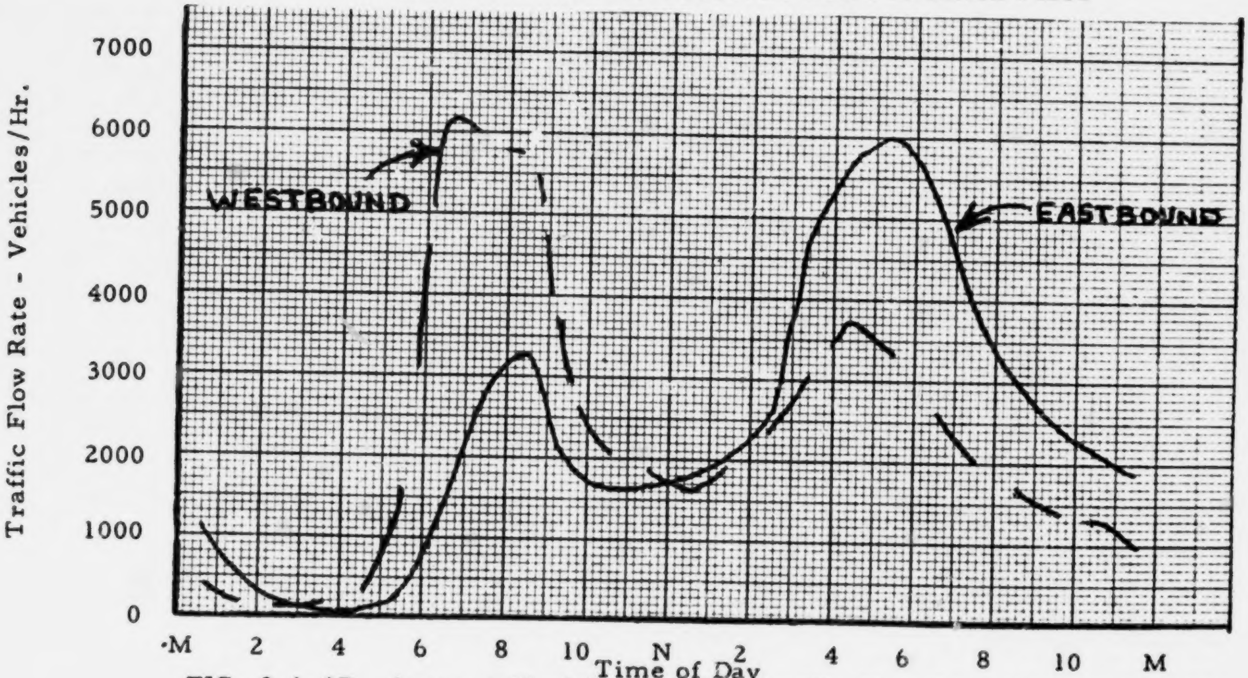


FIG. 2.1-8B Average Weekday Diurnal Traffic Flow Rate Characteristics on a Doubly Cantilever Covered Roadway, Open in the Top Middle - Grand Central Parkway at Parsons Boulevard

FIG. 2.1-8 DIURNAL CHARACTERISTICS OF TRAFFIC FLOW RATE AT TWO CANTILEVER COVERED ROADWAYS

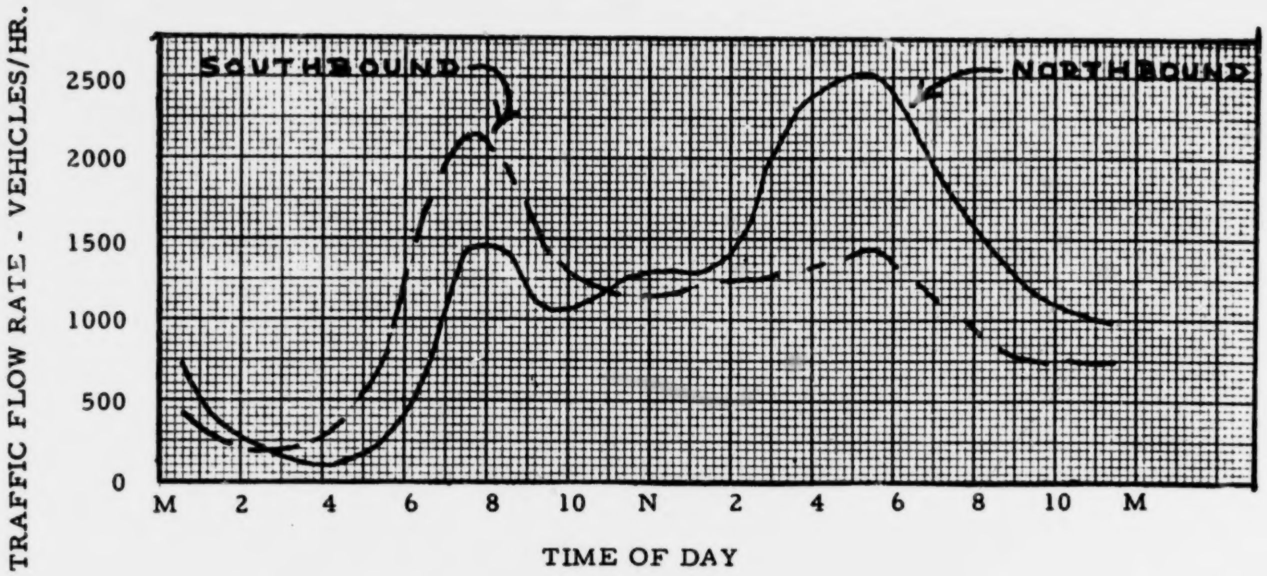


FIG. 2.1-9A Average Weekday Diurnal Traffic Flow Rate Characteristics on Grade Road on Bruckner Expressway Near White Plains Road

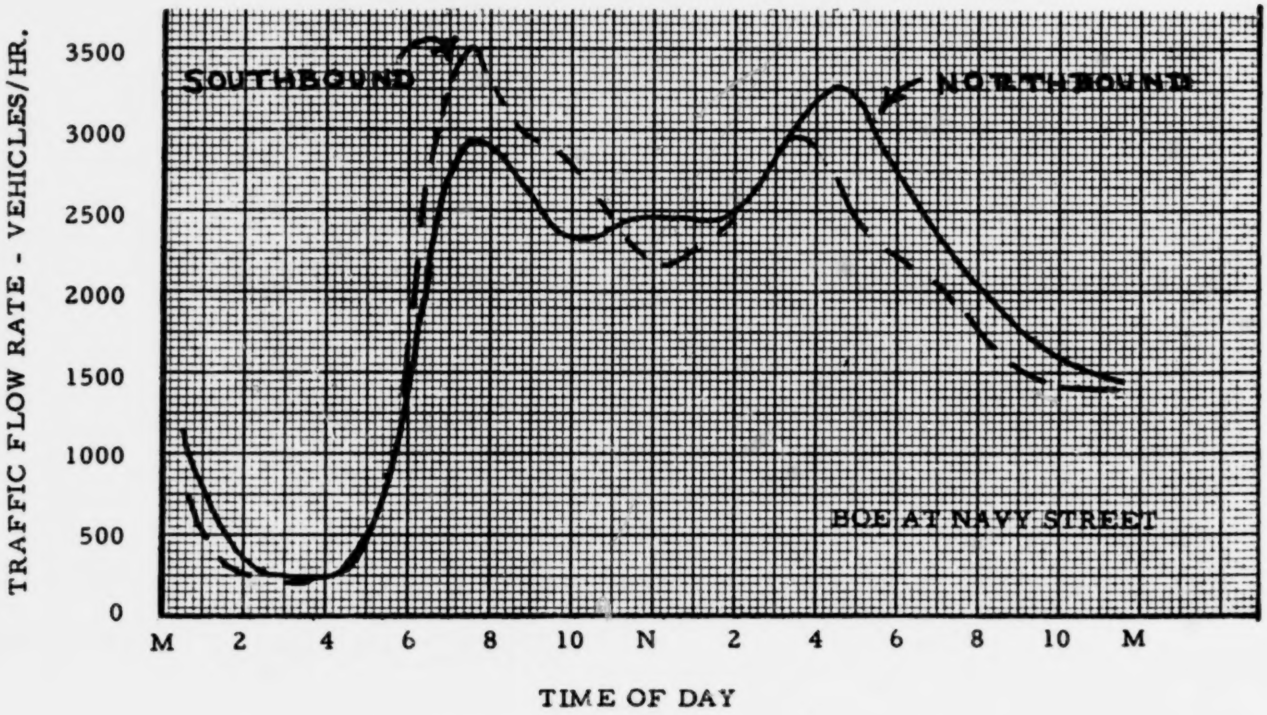


FIG. 2.1-9B Average Weekday Diurnal Traffic Flow Rate Characteristics on Viaduct Roadway on Brooklyn-Queens Expressway at Navy Street

FIG. 2.1-9 DIURNAL CHARACTERISTICS OF TRAFFIC FLOW RATE AT TWO OPEN ROADWAY CONFIGURATIONS

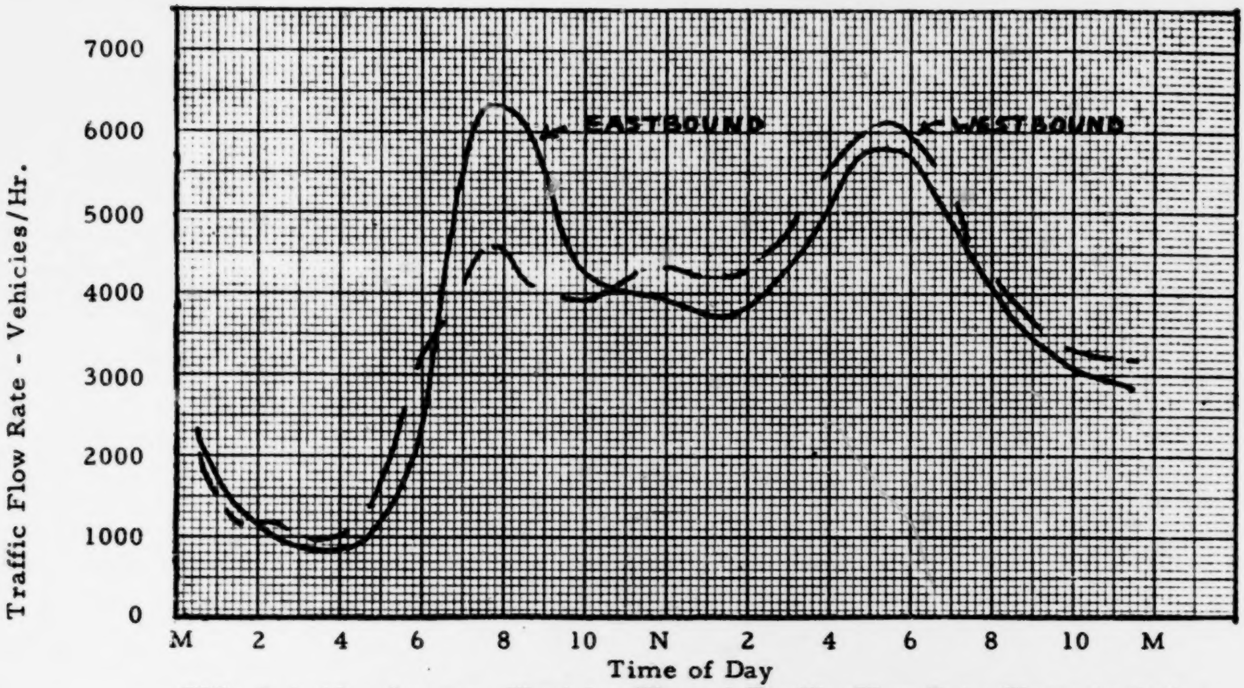


FIG. 2.1-10 Average Weekday Diurnal Traffic Flow Rate Characteristics on an Intermittently Covered Roadway - Trans Manhattan Expressway at George Washington Bridge Plaza

2.1.3 Horizontal and Vertical Carbon Monoxide Concentration Distribution and Concentration Isopleths

2.1.3.1 Horizontal and Vertical Concentration Profiles

Figures 2.1-11 through 2.1-15 are plots of the horizontal and vertical distributions of carbon monoxide concentration for each of the ten sites. As with the traffic curves, the plots for sites with similar geometry appear on the same page for convenience of comparison. Thus the concentration curves for the three open cuts are given in figures 2.1-11A, 2.1-11B and 2.1-11C. In all cases the concentration values plotted are the weekday means of the hourly averages over the entire monitoring period. Generally, in figures 2.1-11 through 2.1-15, hourly concentrations for four hours of the day were chosen to illustrate the daily spread of values. The horizontal profiles represent sensor values across the road at a height chosen to best illustrate the shape of the profile. The vertical profiles generally represent sensor values in the vertical plane which showed the highest concentration. The direction of traffic flow at each site is shown on the horizontal profile plots. The plane of vertical profiles are indicated on the vertical plots. The average weekday diurnal concentration curves for each sensor, not shown in this section, exhibit characteristics similar to their traffic counterparts with two characteristic rush hour peaks, a slight dip between rush hours and a pronounced relative minimum between two and four A. M.

Before examining figures 2.1-11 through 2.1-15 in detail, it is well to summarize what the data might reasonably be expected to show. This summary will then serve as a basis for comparison with the measured data.

The horizontal concentration profiles should tend to show peak values at impermeable walls because the pollutant will tend to accumulate there. Thus in an open cut one would expect relative maxima at the two walls and accordingly a relative minimum at or near the center of the road. The two maxima will not, in general, be of equal magnitude, but rather their relative magnitudes can be expected to depend on the traffic volume on each side of the median strip and on the cross roadway component of wind.

The horizontal profile at a site with a wall on side of the road and the other side open to ventilation, can be expected to show a peak at the wall and a decay in concentration with distance from the wall approaching the background level, in the absence of other sources, when the distance from the wall becomes very large.

The horizontal concentration profile at a site which is open to ventilation at both sides can be expected to show a relative maximum at or near the middle of the road and a decay in both directions across the road. It is obviously much easier for the pollutant to diffuse away from the source than across the median strip into the lanes of traffic travelling in the opposite direction.

The vertical concentration profile above a road which is open to ventilation at the top can be expected to exhibit a decay in concentration with height above the mean exhaust plane of the vehicles and to approach the background level when the height above the source becomes large. It would not be unreasonable to expect an exponential decay of concentration with height. Indeed Georgii et al (Ref. 1) have reported such a relation in measurements made in Frankfort, Germany.

In covered roadways, the presence of the impermeable ceiling would require that the vertical component of the concentration gradient be zero at the ceiling. This would imply a relative maximum at the ceiling if no other means of ventilation exists. In the case of a site such as Sutton Place which is covered, but has one side open to ventilation, it is possible that a relative minimum of concentration could exist at the ceiling.

With this summary of what might be expected at the various site configurations, an examination of the concentration profiles at the three open cut sites in figure 2.1-11 shows that at Hicks Street and Nelson and Jessup Avenues, the horizontal profiles indeed indicate relative maxima at the walls and a relative minimum at or near the center of the road. The vertical concentration profiles at these two sites show a decay with height above the road and the Nelson and Jessup Avenues site actually indicates a vertical profile shape that is consistent with an exponential decay.

The Canal Street site infigure 2.1-11C does not appear to behave quite like the other two open cuts. The horizontal profile appears to be roughly sinusoidal in shape. The vertical concentration profile shows a decay with height for the first 27 feet, then an increase and then a decay. This seems to indicate that an inversion layer exists along the building face.

Figure 2.1-12A shows the horizontal and vertical concentration profiles in the short, unventilated tunnel at Hugh Grant Circle. As can be seen from the figure, the horizontal profile shows relative maxima at the walls and a relative minimum at mid-road for most hours of the day. This behavior is as expected. The vertical profile indicates an increase of concentration with height for the first ten feet and then a leveling off. This indicates a fairly thick accumulation at the ceiling more or less as expected.

The Brooklyn Battery Tunnel which is blower ventilated does not exhibit a consistent concentration profile as can be seen from figure 2.1-12B. This is almost certainly the result of the forced ventilation blower cycle.

The two cantilever covered roadway sites exhibit the concentration profiles that one would expect. The covered on top, open at one side configuration at Sutton Place shows the expected maximum at the wall and a roughly Gaussian shaped horizontal profile decaying towards the

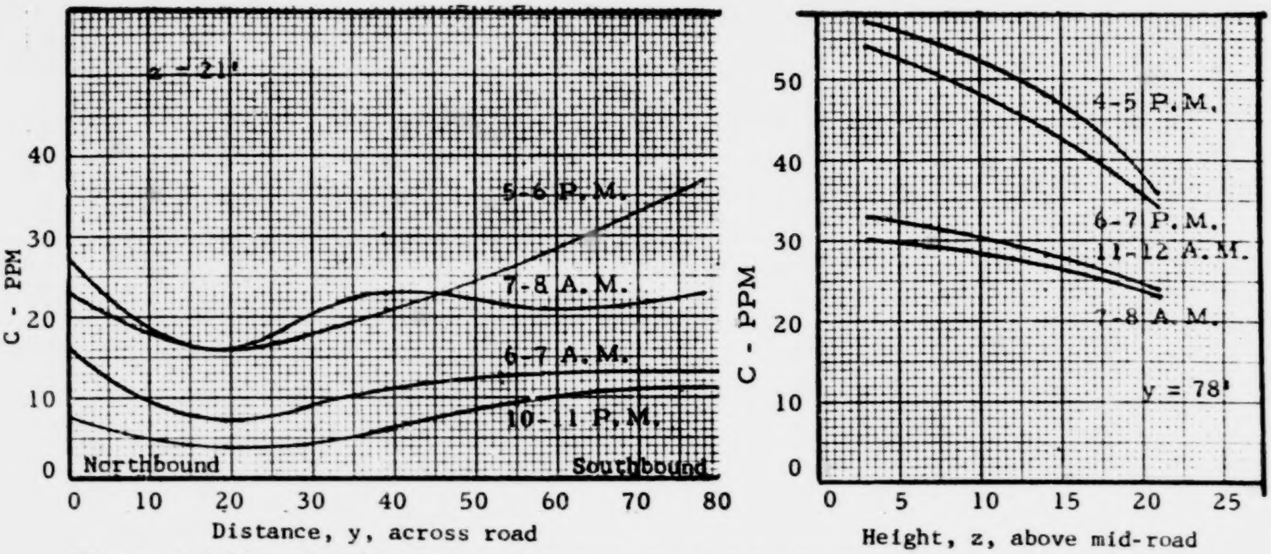


Figure 2.1-11A - Brooklyn Queens Expressway at Hicks Street

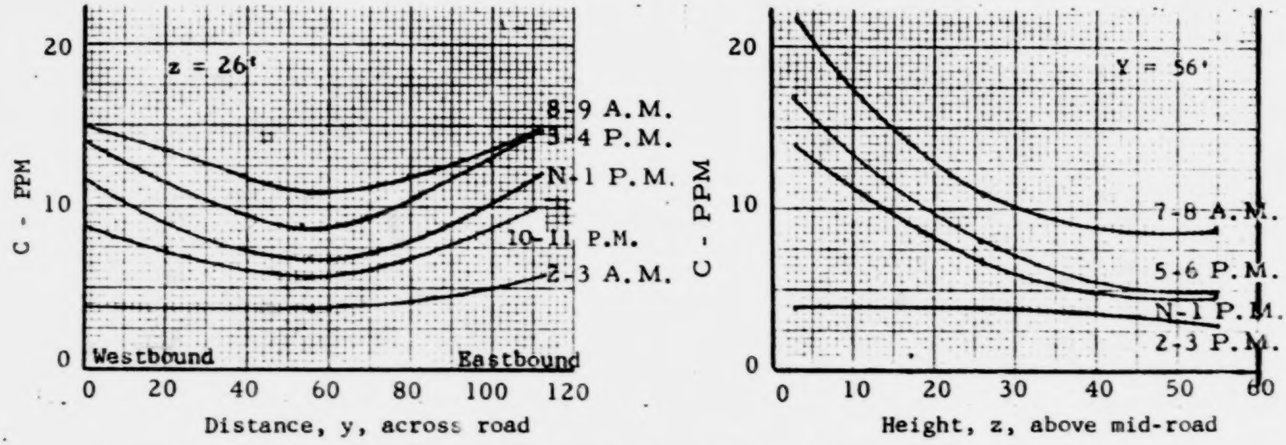


Figure 2.1-11B - Cross Bronx Expressway at Nelson & Jessup Avenues

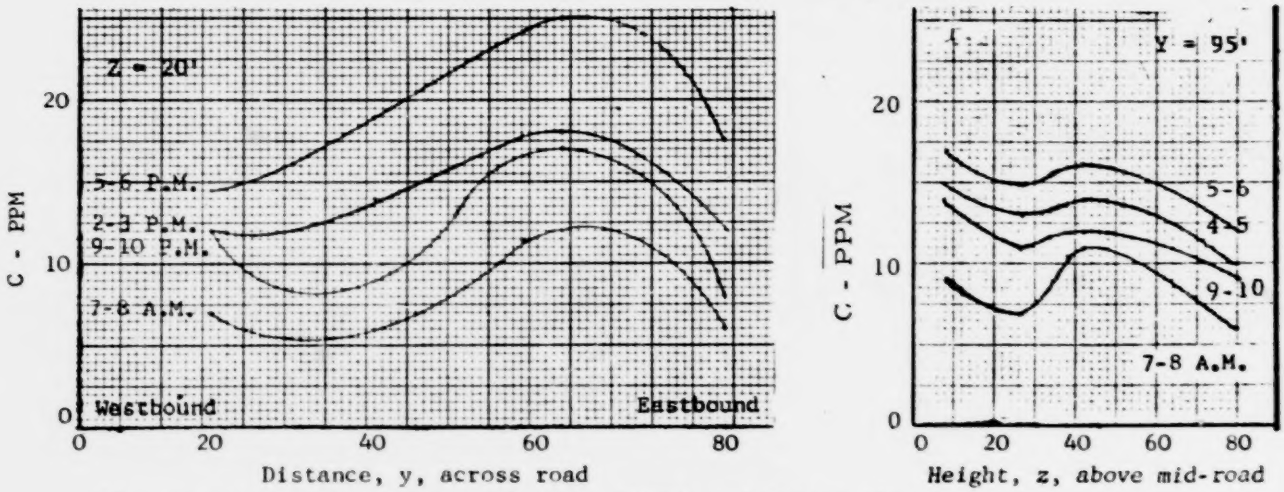
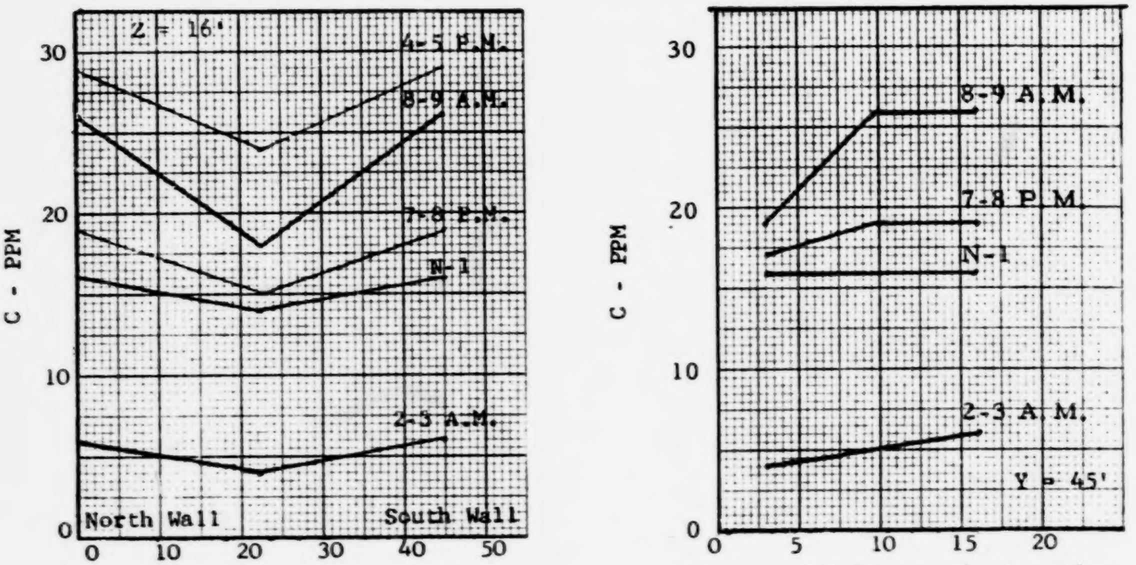


Figure 2.1-11C - Canal Street between Church and Mercer Streets

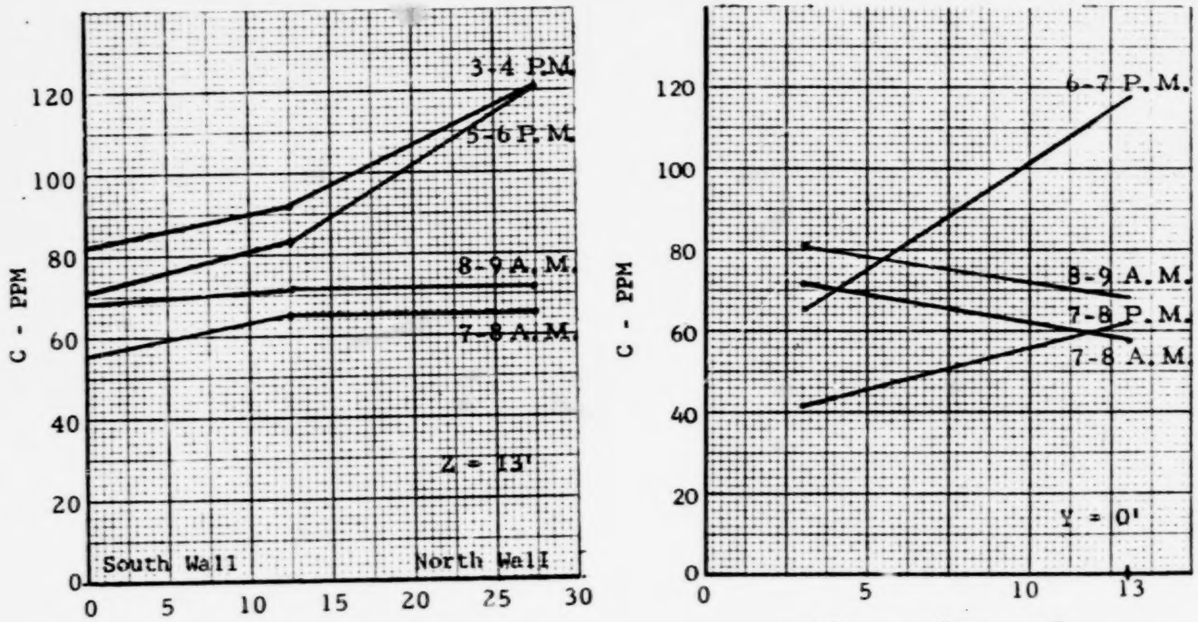
FIGURE 2.1-11 HORIZONTAL & VERTICAL CONCENTRATION PROFILES IN THREE OPEN CUTS



Horizontal Concentration Profile Across Ceiling 16' Above Road

Vertical Concentration Profile Along Left Lane (South) Wall

Figure 2.1-12A - Cross Bronx Expressway at Hugh Grant Circle - Westbound Tube

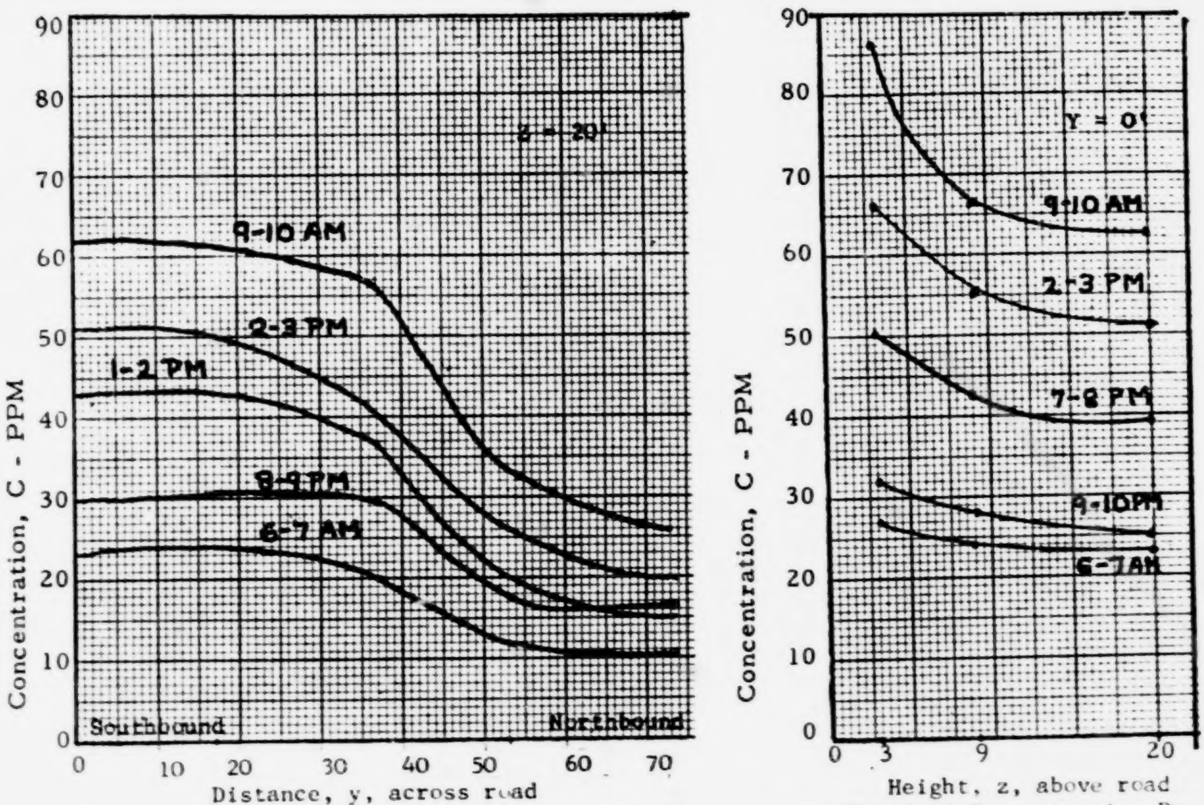


Horizontal Concentration Profile Across Ceiling 13' Above Road

Vertical Concentration Profile Along Right Lane (South) Wall

Figure 2.1-12B - Brooklyn Battery Tunnel - Brooklyn Bound Tube

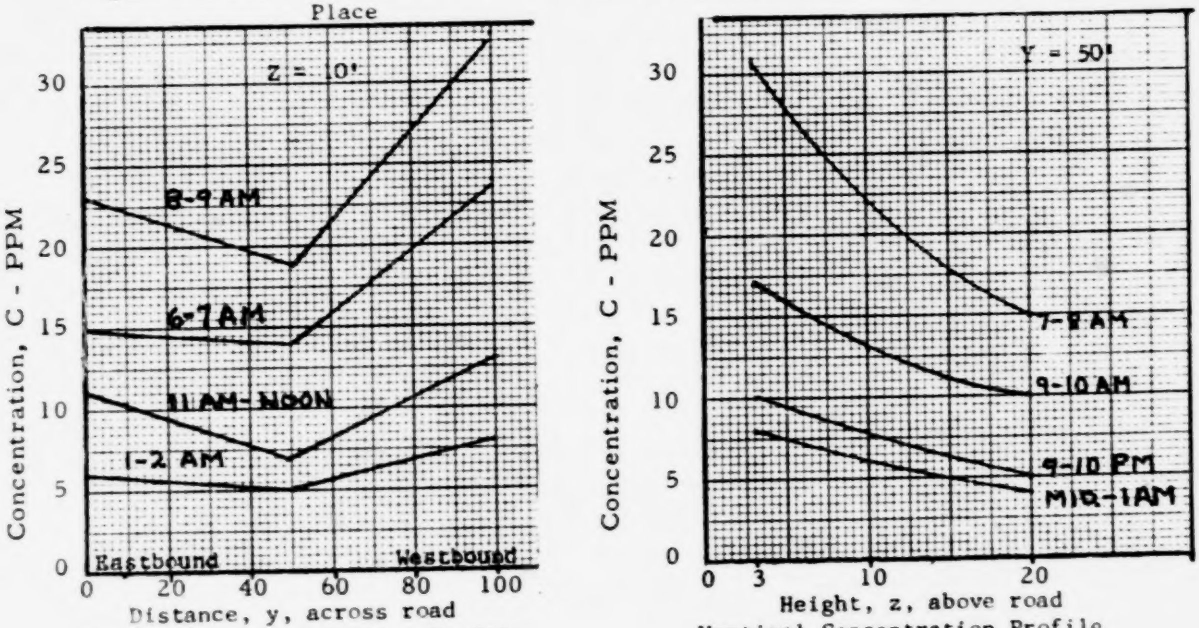
FIGURE 2.1-12 HORIZONTAL AND VERTICAL CONCENTRATION PROFILES IN TWO TUNNELS



Horizontal Concentration Profile Across Ceiling

Vertical Concentration Profile Along Wall

Figure 2.1-13A - Cantilever covered road, open at one side - FDR Drive at Sutton Place

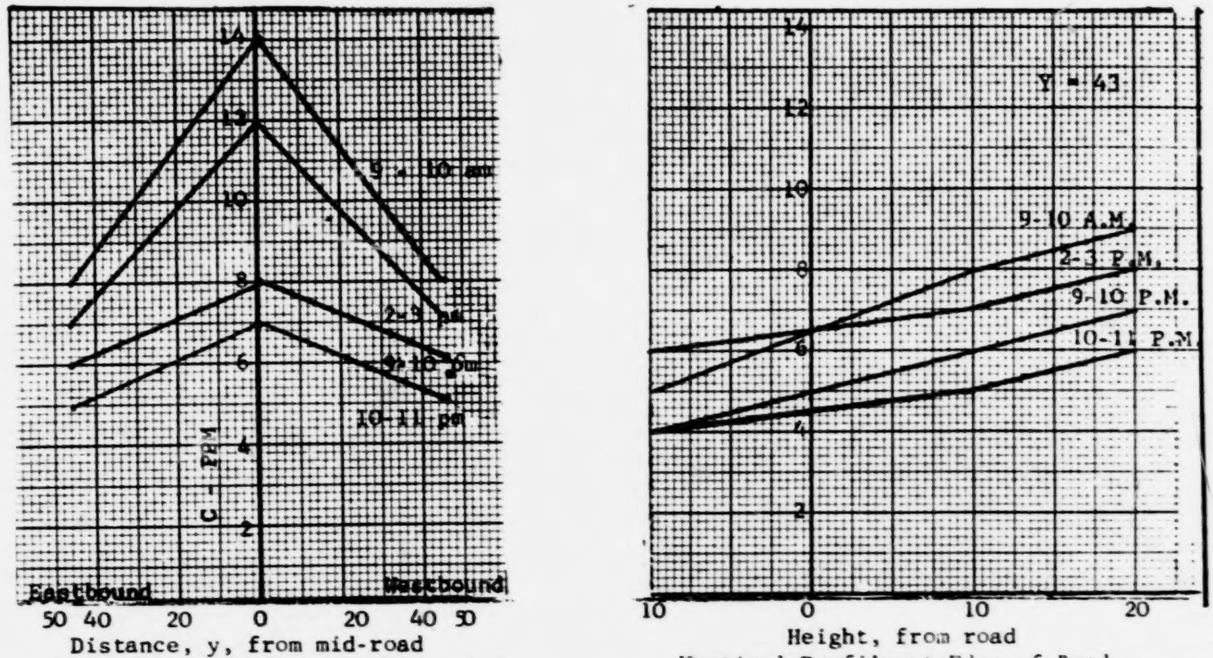


Horizontal Concentration Profile Across Roadway at 10 foot level

Vertical Concentration Profile At Middle of Road

Figure 2.1-13B - Doubly cantilever covered roadway, open in the top middle, Grand Central Parkway at Parsons Boulevard

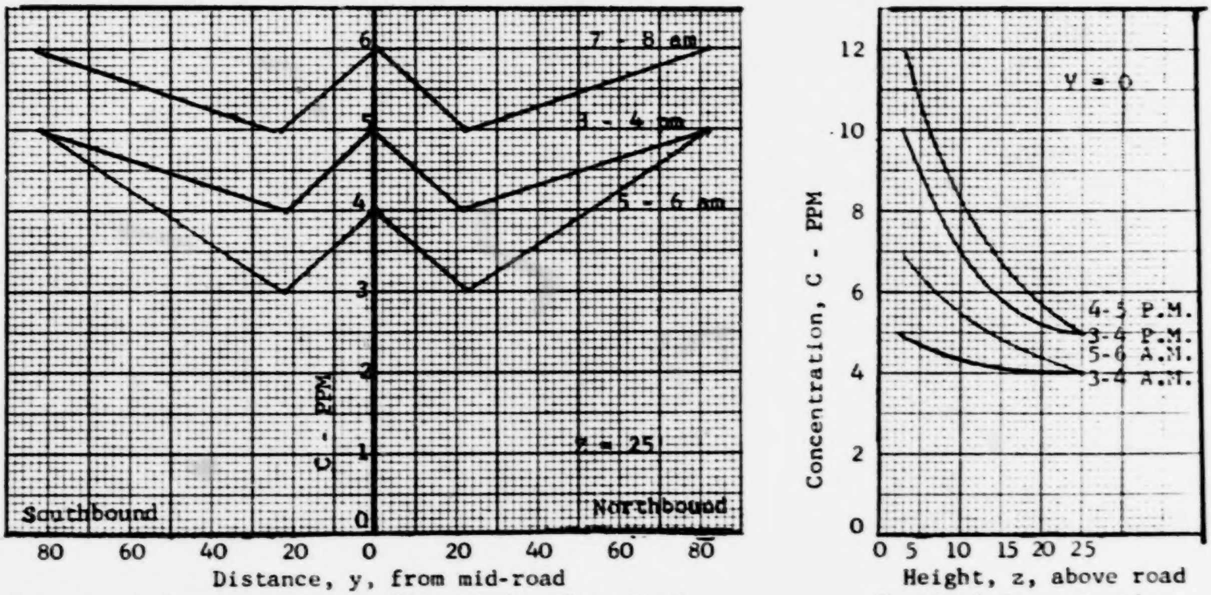
FIGURE 2.1-13 HORIZONTAL & VERTICAL CONCENTRATION PROFILES ON TWO CANTILEVER COVERED ROADS



Horizontal Concentration Profile 10 ft. above road

Vertical Profile at Edge of Road

Figure 2.1-14A - Viaduct road - Brooklyn Queens Expressway at Park & Navy Streets

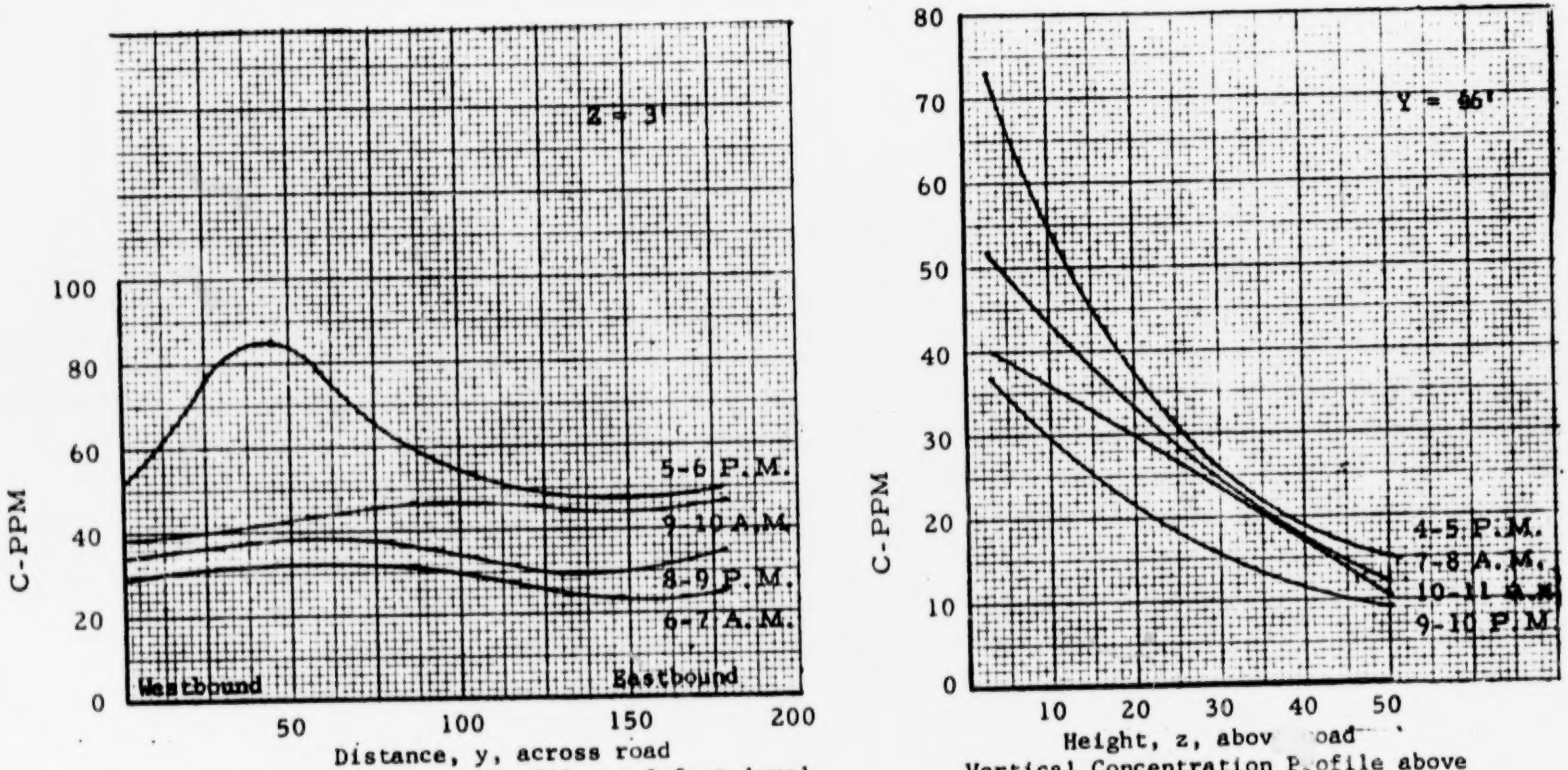


Horizontal Concentration Profile 25 ft. Above Road

Vertical Concentration Profile in Middle or Road

Figure 2.1-14B - Grade Road - Bruckner Expressway near White Plains Road

FIGURE 2.1-14 HORIZONTAL & VERTICAL CONCENTRATION PROFILES AT TWO OPEN ROADWAY SITES



Horizontal Concentration Profile at 3 foot level

Vertical Concentration Profile above middle of westbound lanes

FIGURE 2.1-15 HORIZONTAL & VERTICAL CONCENTRATION PROFILES AT AN INTERMITTENTLY COVERED ROADWAY - TRANS MANHATTAN EXPRESSWAY AT GEORGE WASHINGTON BRIDGE PLAZA

open side. The vertical concentration profile decays with height and has its smallest value at the ceiling. The doubly cantilevered road, open in the top middle, at Parsons Boulevard shows a horizontal concentration profile with maxima at the walls and a minimum in the middle. The vertical profile in mid-road shows an exponential-like decay with height below the opening in the roof. The concentration values in the two upper corners were the highest concentrations recorded at the site.

Both the open roadway configurations in figure 2.1-14 show horizontal concentration profiles which peak at mid-road as expected. The rise in concentration at both sides of the road at the Bruckner Expressway site is almost certainly caused by the heavy traffic on the service roads on each side. The vertical concentration profile at the Bruckner Expressway shows the expected exponential-like decay. The vertical gradient of the viaduct road at Park and Navy Streets exhibits a linear characteristic at the edge of the roadway. It is entirely possible that the concentrations measured in this vertical plane are predominantly background influence.

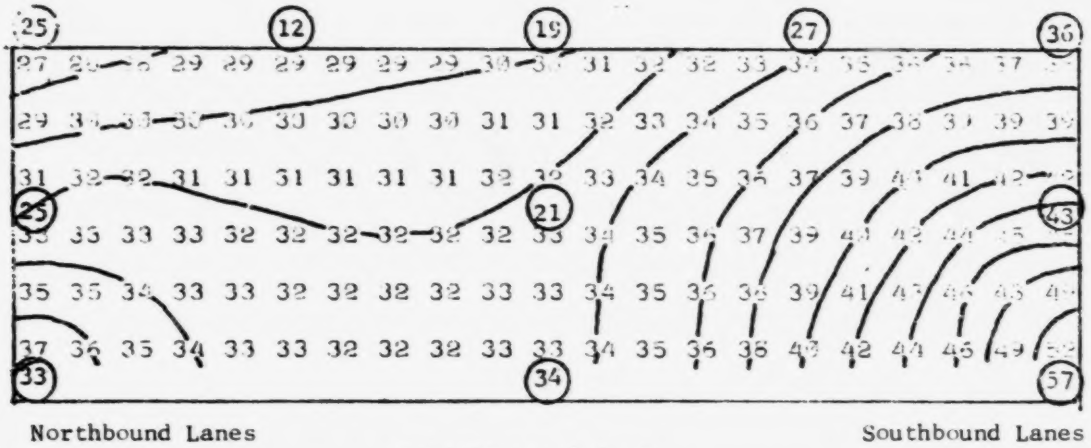
The vertical concentration profile at the intermittently covered road in figure 2.1-15 exhibits an exponential-like decay as expected for an open top configuration. The horizontal concentration profile does not appear to have a consistent pattern.

2.1.3.2 Concentration Isopleths

In addition to the actual concentration spatial profiles presented in figures 2.1-11 through 2.1-15, a set of concentration isopleths has been plotted for each of the sites. The isopleths were computed from an empirical model which assumes that each lane of traffic constitutes a line source of carbon monoxide. Then the concentration at any point near the roadway consists of the superposition of contributions from each of the line sources. It is further assumed in the empirical model that concentration decays exponentially with radial distance from the line source in each lane, and that the horizontal plane in which the vehicle exhausts lie, coincides with a plane three feet above the road containing the lowest level probes at each site. Based on these assumptions and an empirically determined decay factor, the concentration of each of the postulated line sources was determined. From these concentrations and the radial exponential decay law mentioned above, the isopleth plots were computed for several hours at each site. This model and the isopleths are presented and discussed in detail in Section 3 of this report. Figures 2.1-16 through 2.1-21 are presented here, however, as a brief summary showing the isopleth plot for a single hour at each site. The direction of traffic flow at each site is as shown on the plots. The values actually measured by the probes are indicated on the figures for reference. It can be seen that reasonably good agreement exists between measured and computed values.

2.1.4 Meteorological Patterns at the Study Sites

Table 2.1.2 gives a summary of the general meteorological picture at each of the sites. More complete descriptions appear in Section 4.



Grid Size = 4 feet
Shallow Cut - Brooklyn Queens Expressway at Hicks Street - 1600-1700 hours

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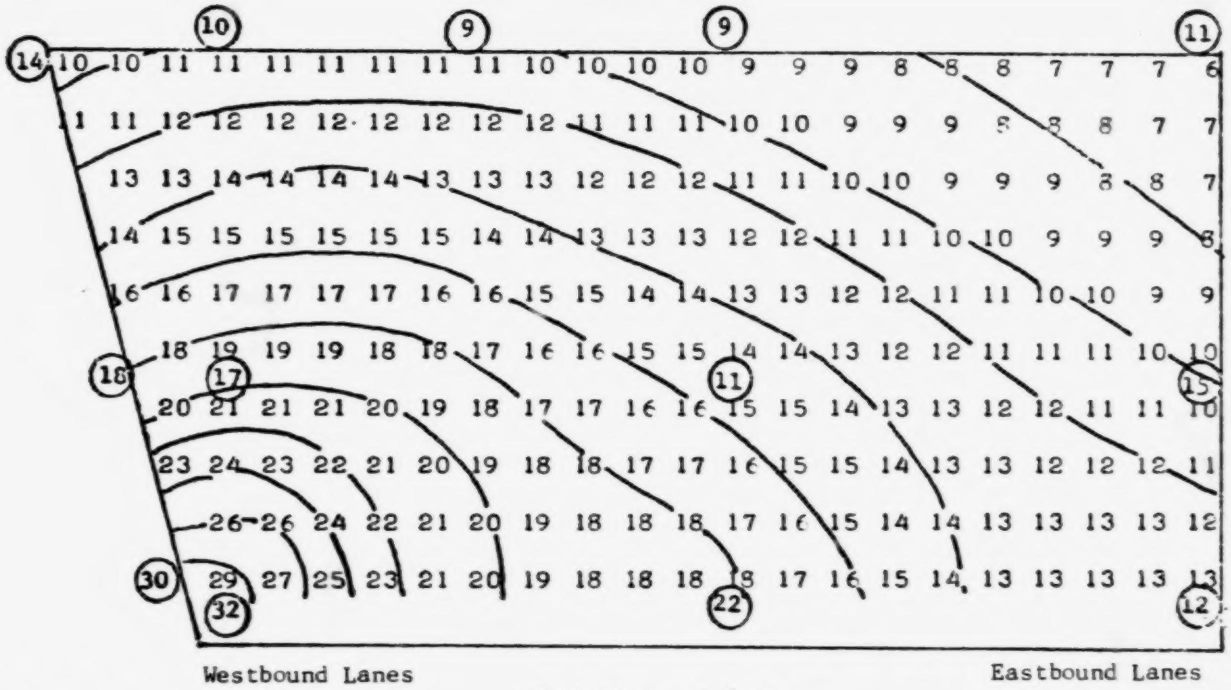
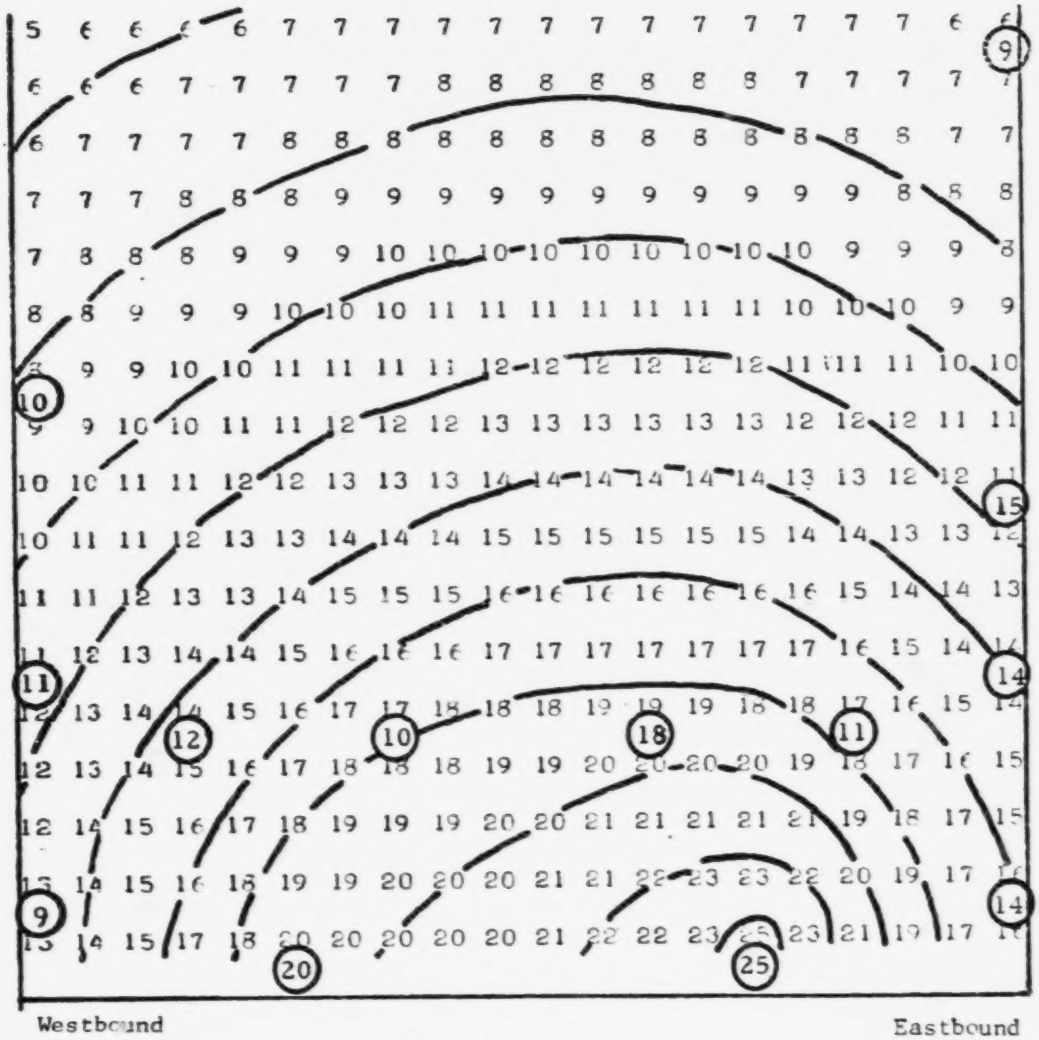


Grid Size = 6 feet
Deep Cut - Cross Bronx Expressway at Nelson & Jessup Avenues - 0700-0800 hours

Figure 2.1-16 Concentration Isopleths at Two Open Cuts
(Measured Values enclosed in O)



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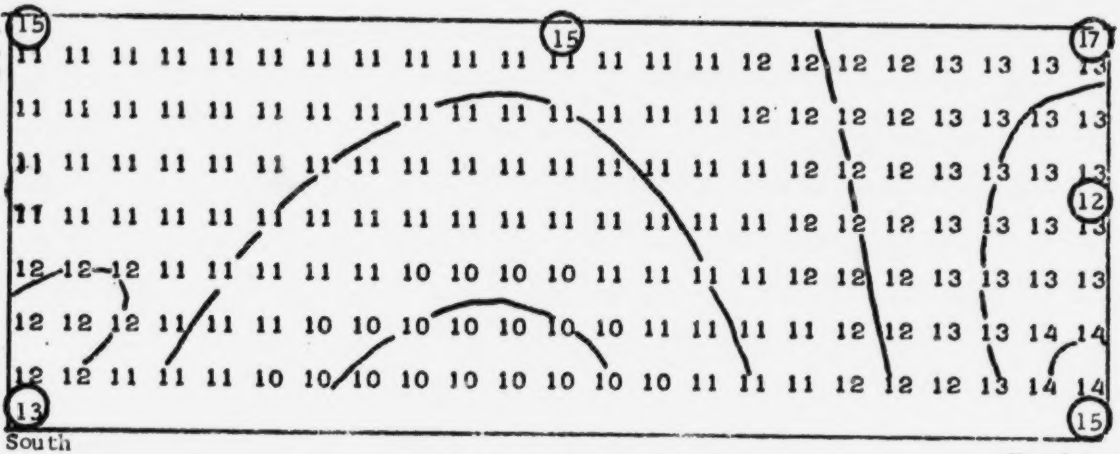
13	14	15	17	18	20	20	20	20	20	21	22	22	23	25	23	21	19	17	16

Grid Size = 5 feet.
Canal Street between Church & Mercer Streets - 1200-1300 hours

Figure 2.1-17 Concentration Isopleth in a City Street
(Measured Values Enclosed in O)



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12	12	12	11	11	11	10	10	10	10	10	10	10	11	11	11	11	12	12	13	13	14	14
12	12	11	11	11	10	10	10	10	10	10	10	10	10	11	11	11	12	12	12	13	14	14

Grid Size = 2 feet

A Short Unventilated Tunnel - Cross Bronx Expressway at Hugh J. Grant Circle - Eastbound Tunnel - 0700-0800 hours

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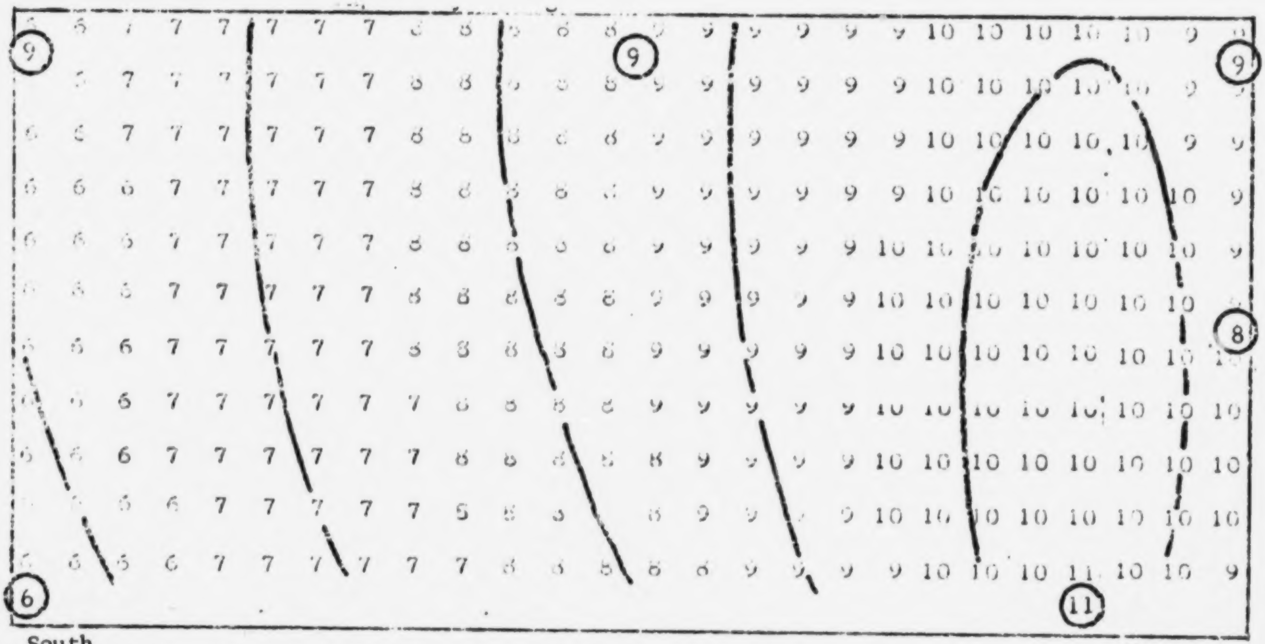

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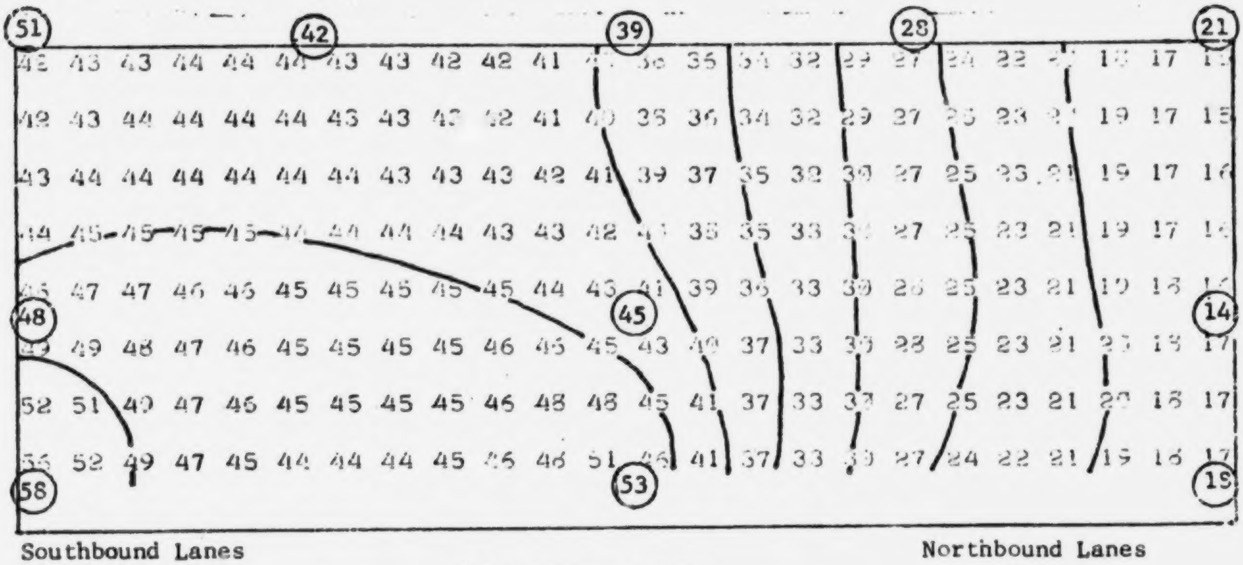
6	6	6	7	7	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	10	10	10	10	10	10
[illegible]	6	6	6	7	7	7	7	7	5	8	8		8	9	9	[illegible]	9	10	10	10	10	10	10	10	10
6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	10	11	10	10	9

Grid Size = 1 foot

Long, Blower Ventilated, Brooklyn Battery Tunnel - Brooklyn Bound Tube - 1600-1700 hours
Values x 10

Figure 2.1-18 Concentration Isopleths in Two Tunnels
(Measured Values Enclosed in O)



Grid Size = 3 feet
A Cantilever Covered Roadway Open at One Side - Franklin D. Roosevelt Drive at Sutton Place - 0700-0800 hours

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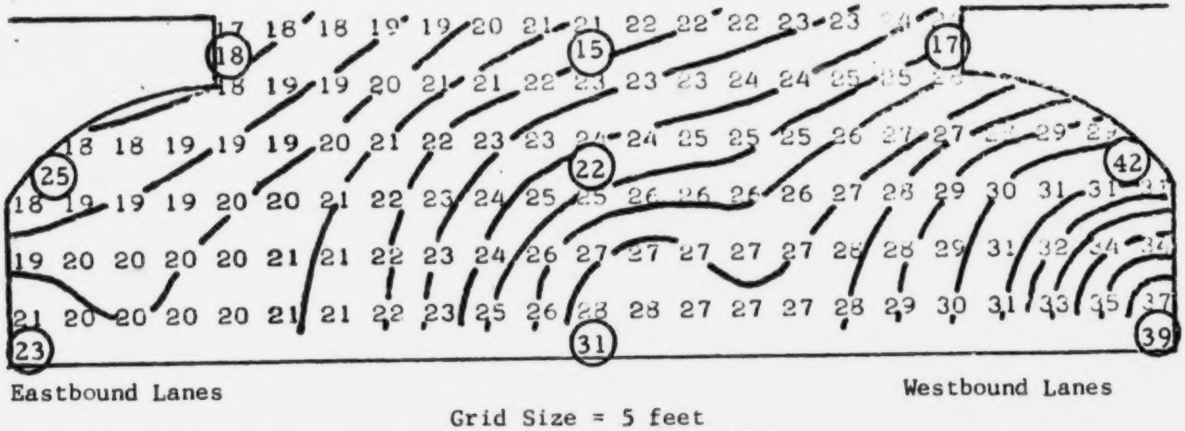
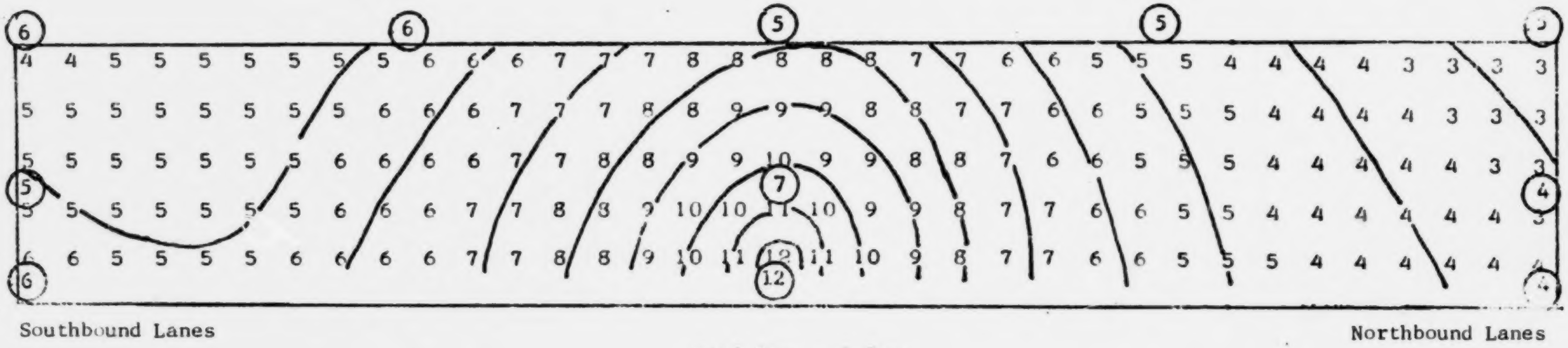


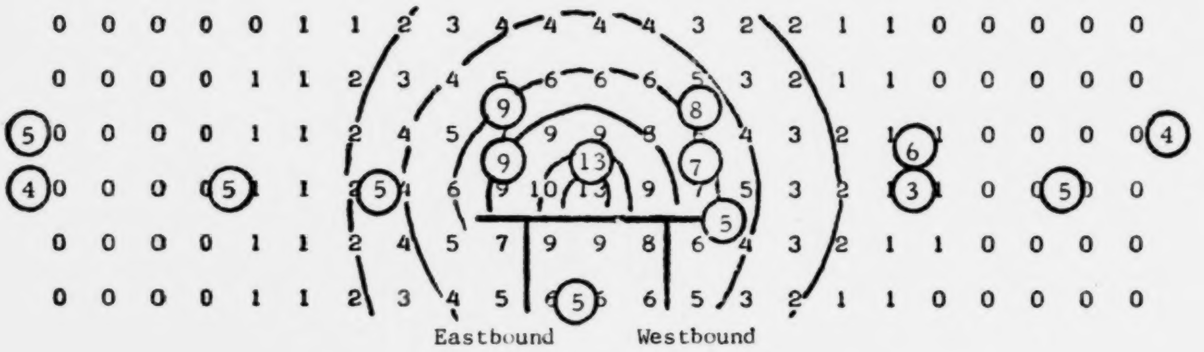
Grid Size = 5 feet
Double Cantilever Covered Roadway, Open in the Top Middle-Grand Central Parkway at Parsons Boulevard - 0700-0800 hours

Figure 2.1-19 Concentration Isopleths at Two Cantilever Covered Roads (Measured Values enclosed in O)



Grid Size = 5 feet

Grade Roadway - Bruckner Blvd. near White Plains Road - 1600-1700 hours



Grid Size = 20 feet

Viaduct Roadway - Brooklyn Queens Expressway at Park & Navy Street - 1600-1700 hours

Figure 2.1-20 Concentration Isopleths at Two Open Roadways
(Measured Values enclosed in O)

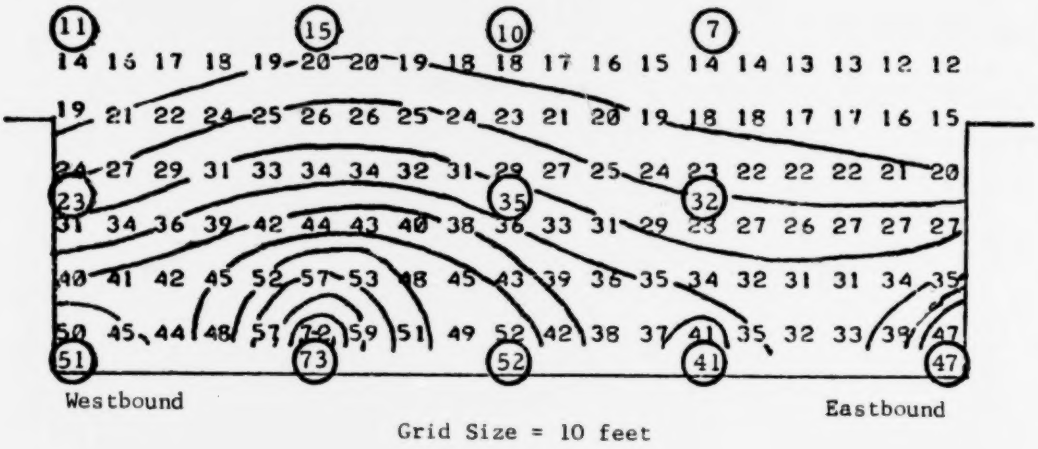


Figure 2.1-21 Concentration Isopleth at an Intermittently Covered Road - Trans Manhattan Expressway at George Washington Bridge Plaza - 1600-1700 hours (Measured Values enclosed in O)

TABLE 2.1-2 METEOROLOGICAL SUMMARY

Zero Degrees Azimuth Is Parallel To The Road; Zero Degrees Elevation Is Horizontal

	FDR Dr. at Sutton Place	BQE at Hicks St.	CBE at Grant Circle	CBE at Jessup Ave. (6)	Bruckner Expressway	Grand Central Parkway	BQE at Navy St.	Canal St.	Geo. Wash. Bridge(2)
Vane 1(1)	Over S. B. Lane z = 14'	Median z = 14'	Over Tunnel Exit z = 14'	Median z = 14'	South of Road z = 30'	Service Road z = 25'	North Edge of Road z = 20'	North Roof z = 75'	Westbound Divider z = 14'
Prevailing Azimuth(8)	85°	165°	305°	5°	175°	5°	75°	15°	M
Prevailing Elevation	+15°	- 5°	+ 5°	+ 5°	- 15°	- 5°	- 5°	-15°	+5°
Mean Sigma Azimuth	11.5°	15.9°	35.9°	19.8°	11.2°	11.9°	9.3°	10.8°	M
Mean Sigma Elevation	6.3°	12.5°	19.7°	13.9°	7.6°	8.9°	7.1°	6.8°	7.2°
Mean Wind Speed (mph)	6.4	5.4	4.4	5.5	8.1	3.7	3.3	2.9	2.9
Vane 2(1)	On Trailer	Over Queens-Bound Lanes z = 18'	Median z = 14'		Median z = 14'	Median z = 14'	Median z = 14'	North Trailer z = 14'	
Prevailing Azimuth(8)	5°	175°	175°(4) 325°	M	115°	125°	15°	5°	M
Prevailing Elevation	+ 5°	M(5)	M	M	+ 15°	- 15°	- 5°	+55°(7)	M
Mean Sigma Azimuth	14.3°	17.4°	30.8°	M	14.5°	15.4°	19.8°	9.2°	M
Mean Sigma Elevation	9.1°	M	M	M	10.0°	8.8°	9.9°	7.2°	M
Mean Wind Speed (mph)	3.6	M	5.3(3)	M	4.9	2.5	2.9	2.7	M

TABLE 2.1-2 (NOTES) METEOROLOGICAL SUMMARY

1. For exact vane locations, see Section 4.0
2. This vane was designated vane 4
3. Based on only 1 day of available data
4. Bimodal with peaks of identical magnitude - most other azimuth distributions were also bimodal
5. "M" indicates missing or insufficient data
6. Data at this site was taken with makeshift vector vane tail and therefore sigma channels should not be used in intersite comparisons
7. Broken and unbalanced tail section caused large positive values
8. Parallel to the road.

2.1.5 Hydrocarbon Concentrations at the Study Sites

The data pertaining to the hydrocarbon concentrations at the study sites are tabulated in Appendix B. In general, the diurnal pattern at all sites showed increased concentrations during the daytime and a general reflection of rush hour traffic peaks. The highest concentrations occurred at the Canal Street and George Washington Bridge Plaza sites. Bruckner Expressway and the Brooklyn Queen Expressway at Nelson and Jessup Avenues showed the lowest hydrocarbons. The average daily concentrations at each of the sites is shown on Table 2.3-1.

Figure 2.1-22 shows the effect of the average hourly traffic flow rate on the change in hydrocarbon concentrations at the nine sites measured. The city street, Canal Street between Church and Mercer Streets, exhibits a marked change in hydrocarbons with small traffic variations. The other sites show much lower changes in concentration with increases in traffic flow. The curves for all nine sites suggest that the hydrocarbon concentrations at low traffic flow rates are more a function of background concentration than traffic flow at the site.

2.1.6 Particulate Concentrations and Trace Metals at the Study Sites

The range of particulate concentrations recorded at each site is included in Table 2.3-1. These data represent differing number of samples at each site and were taken at varying distances from the test roadways. The average particulate concentration for all sites was 164 $\mu g/m^3$ at an average distance of 108 feet.

Since the particulate sampler was physically located outside the confines of the test roadway, no firm conclusions can be derived on the influence of site configuration on particulates. Figure 2.1-23 shows the average concentration recorded at each of the sites (except BQE at Park and Navy at which 122 $\mu g/m^3$ were measured, 500 feet from the roadway) versus the horizontal distance between the Hi Vol Sampler and the middle of the roadway. Valid data at two distances from the test roadway is available from only the FDR site. A reduction in particulate concentration did occur at that site with distance. As can be seen from Figure 2.1-24, configuration appears to be more significant than average daily traffic volume. (Two way traffic data was used for all sites except the Brooklyn Battery Tunnel).

The analysis of the particulates for trace metals showed that lead was higher than all other metals at all test sites. As seen in Table 2.1-3 Canal Street with 3.7 $\mu g/m^3$ was highest, while the 3.4 $\mu g/m^3$ measurement at the George Washington Bridge Plaza was the next.

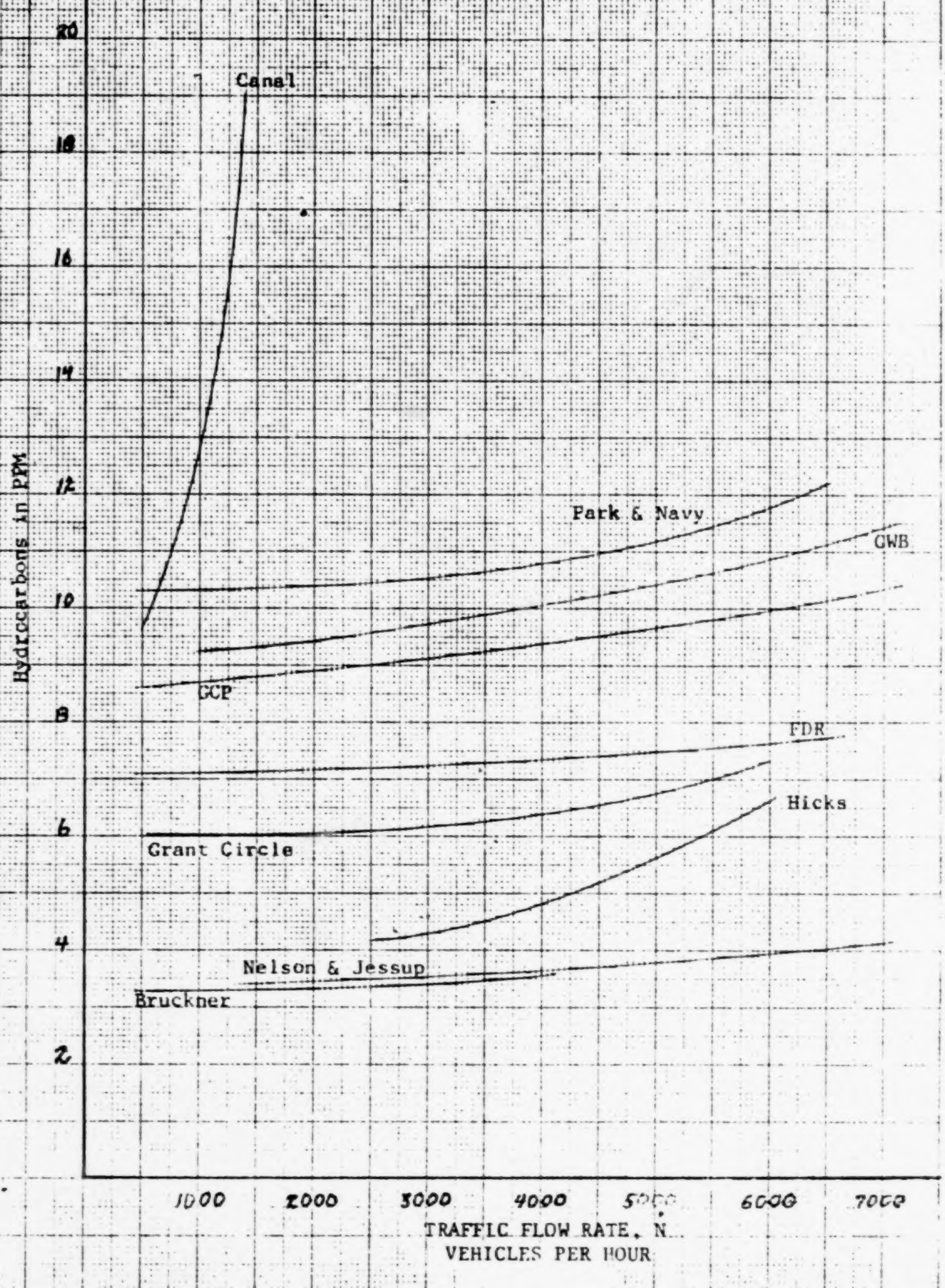
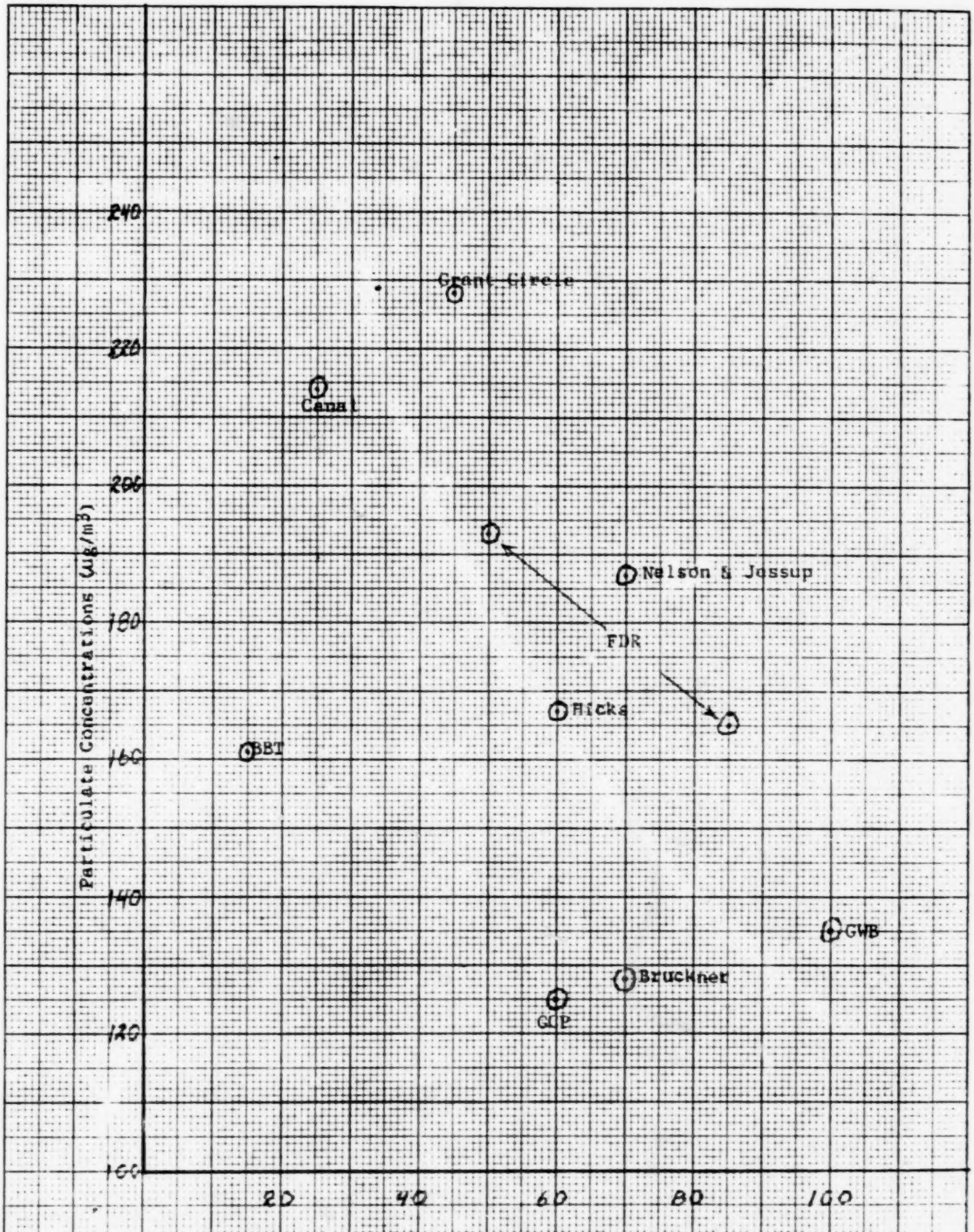


Figure 2.1-22 Hydrocarbons vs Traffic Flow Rate



Horizontal distance from middle of road (feet)

Figure 2.1-23 Particulate concentration vs distance

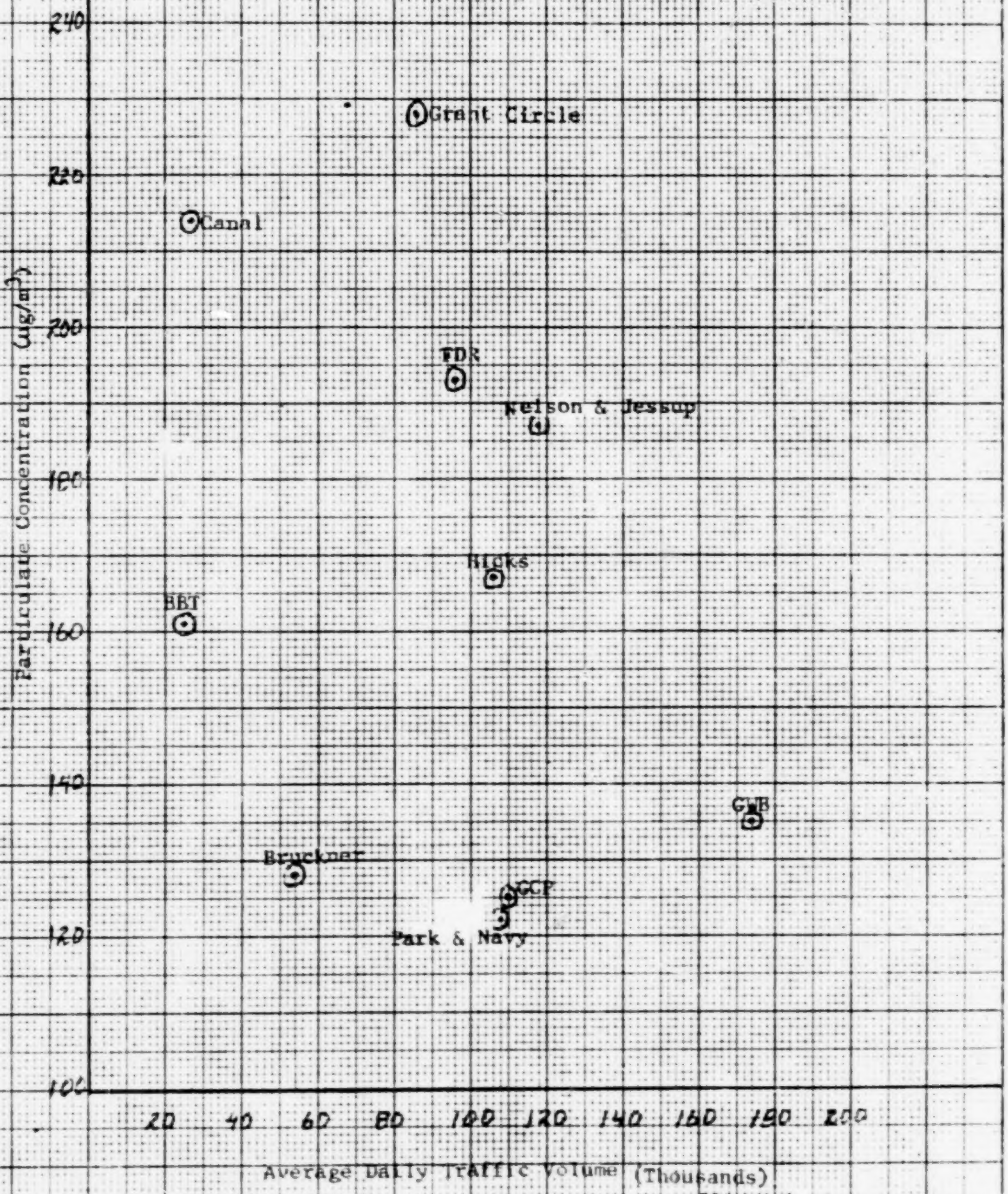


Figure 2.1-24 Particulate Concentration vs Traffic Volume

Site	Trace Metals							
	Pb	Ni	Cu	Fe	Cd	Mn	Cr	Zn
FDR Drive	2.31	T	.101	1.49	.002	.006	T	-
BBT	3.07	.021	.060	1.04	.005	.016	T	.271
Hicks St.	2.69	.006	.046	0.91	.002	.022	T	-
Grant Circle			No Data					
Nelson & Jessup	3.02	T	.179	0.98	.006	.019	T	.257
Bruckner	2.38	T	.103	1.27	.004	.022	T	.154
Grand Central Py.	2.53	T	.240	1.14	.005	.031	T	.118
Park & Navy	2.31	T	.111	.067	.006	.016	T	-
Canal St.	3.66	.029	.154	1.27	.005	.017	T	-
GWB Plaza	3.40	.013	.152	1.64	.003	.030	T	-
Ave.	2.82	.016	.127	1.16	.004	.020	T	.200

Table 2.1-3 Trace Metals $\mu g/m^3$

2.2 Traffic Air Quality Relationships

The basic intent of this section is to present nomographs which provide highway designers with gross estimates of the CO concentration to be expected for various roadway configurations. Figures 2.2-1 to 2.2-10 present representative relationships of CO concentration vs traffic flow rate for the ten sites monitored during this study. The CO values shown in the curves are those of the vertical plane of probes reflecting the maximum values. The traffic values shown are those of the total traffic involved. The Brooklyn Battery Tunnel and Hugh J. Grant sites show the one way traffic passing thru the westbound tubes. The other eight sites show the two way traffic traveling on the roadways.

Sites such as FDR Drive, Brooklyn Battery Tunnel, Hugh J. Grant Circle, Canal Street and Hicks Street show curves with steep slopes indicating strong sensitivity of roadway configurations to traffic volume. This is to be expected from configurations which tend to limit the dilution effect of local meteorology. Conversely, the more open sites, such as Bruckner Expressway, show curves with a small slope.

The Hugh J. Grant site shows an interesting pattern of an inversion and small vertical gradient. This is probably due to the lack of forced ventilation within the tunnel. The Grand Central Parkway curves show a higher CO concentration at the 10 foot level than at the 3 foot level. This results from the lack of ventilation in the corner of the double cantilever structure. FDR Drive at Sutton Place and the Trans Manhattan Expressway at George Washington Bridge Plaza present the highest concentrations of the 10 sites. This is due both to the geometry of the sites and to the volume of traffic involved. The traffic air quality relationships for the nine sites at which CO concentrations were monitored 3 feet above the roadway surface is shown on Figure 2.2-11.

Figure 2.2-2 for the Brooklyn Battery Tunnel shows the relationship between traffic flow and CO concentration for uni-directional traffic within a tube. Data for the two way traffic periods (when rush hour traffic is handled by three lanes of the tunnel) are omitted to more accurately relate to the westbound traffic count. Bi-directional traffic within a tube is marked by an increase in CO concentration in that tube consistent with opposite direction rush hour periods.

Sites that are characterized by traffic slow downs such as Canal Street and Hicks Street show increased CO concentrations disproportionate to traffic flow. Figure 2.2-12 presents the average weekday diurnal CO concentrations measured across the road at Hicks Street. Both the Hicks Street wall and median strip curves follow the variation in traffic volume. The west wall curve, however, does not relate to the quantity of either the southbound or total traffic. The high afternoon and evening CO concentrations at this wall reflect the slow down of southbound traffic approaching the Brooklyn Battery Tunnel turnoff.

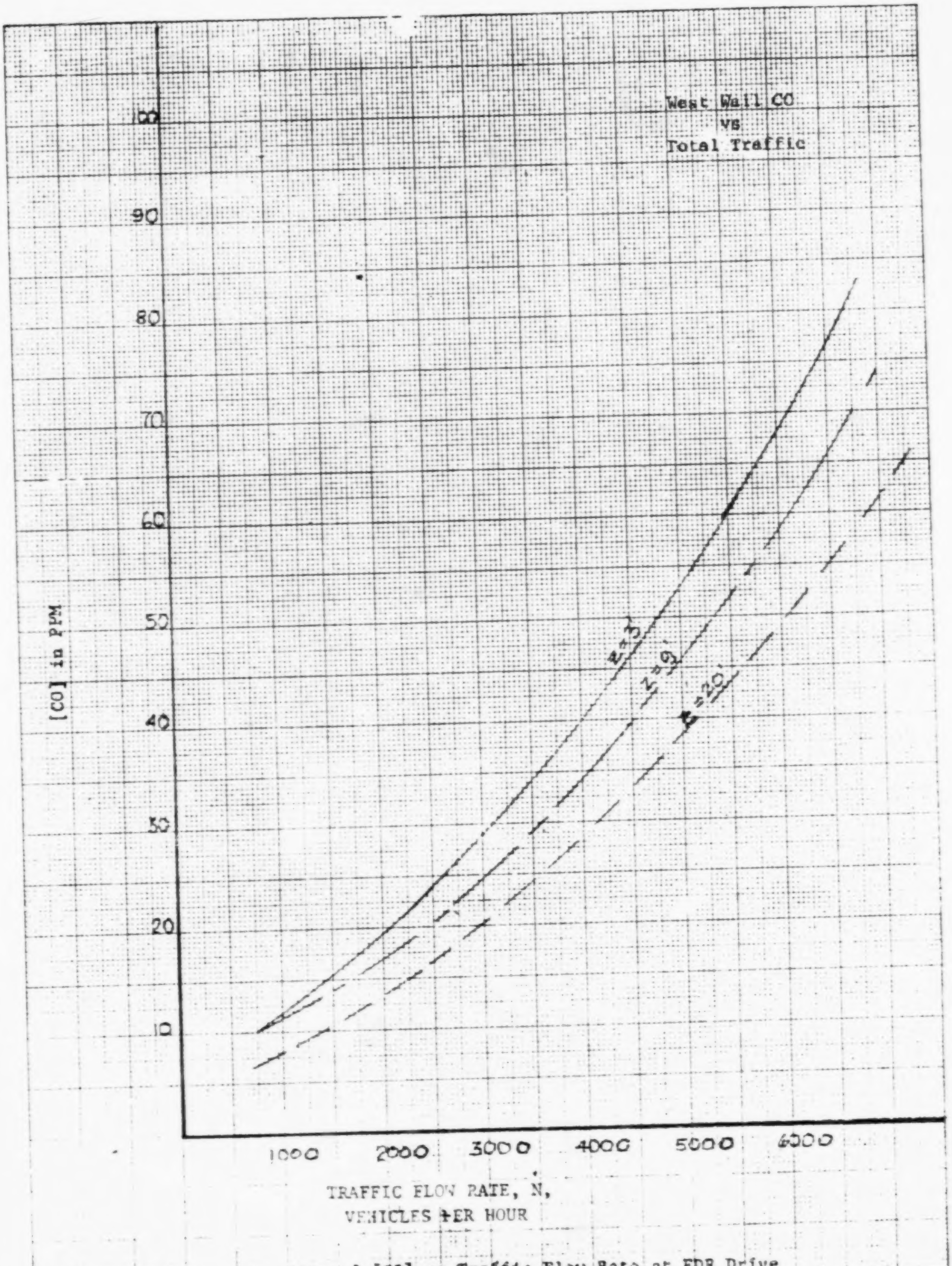


Figure 2.2-1 Profile of [CO] vs Traffic Flow Rate at FDR Drive

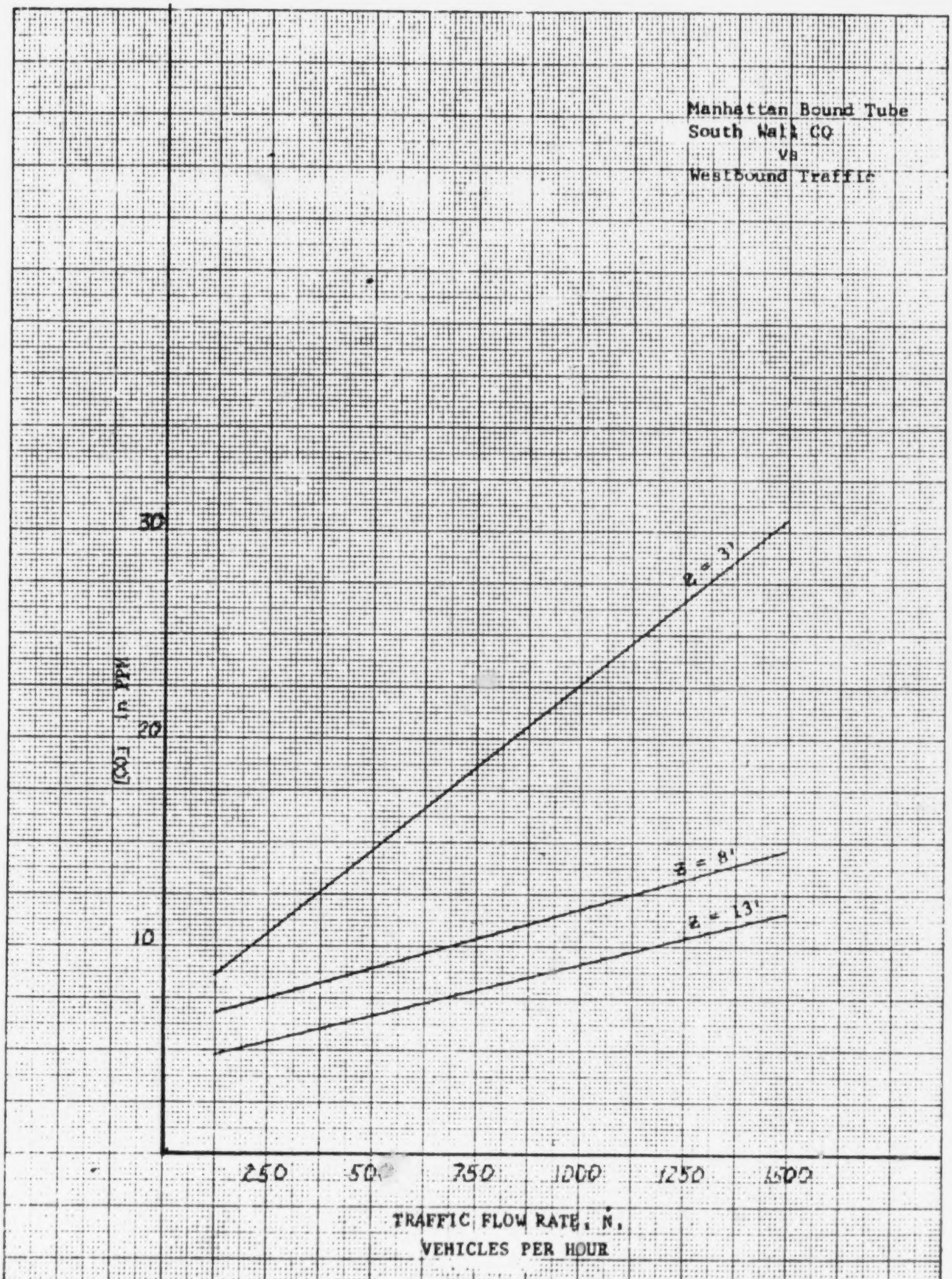


Figure 2.2.2 Profile of [CO] vs Traffic Flow Rate at Brooklyn Battery Tunnel

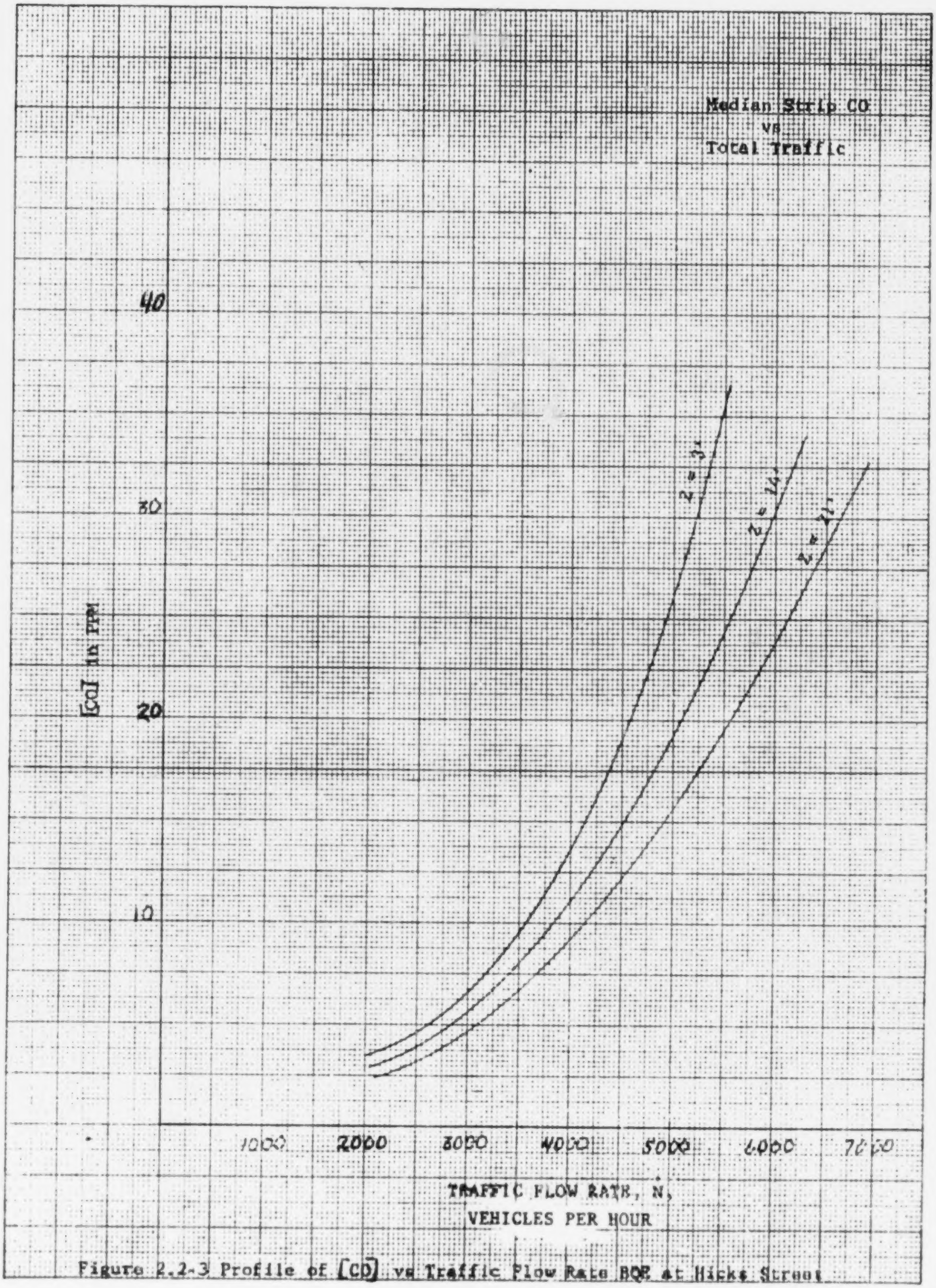


Figure 2.2-3 Profile of [CO] vs Traffic Flow Rate BQE at Hicks Street

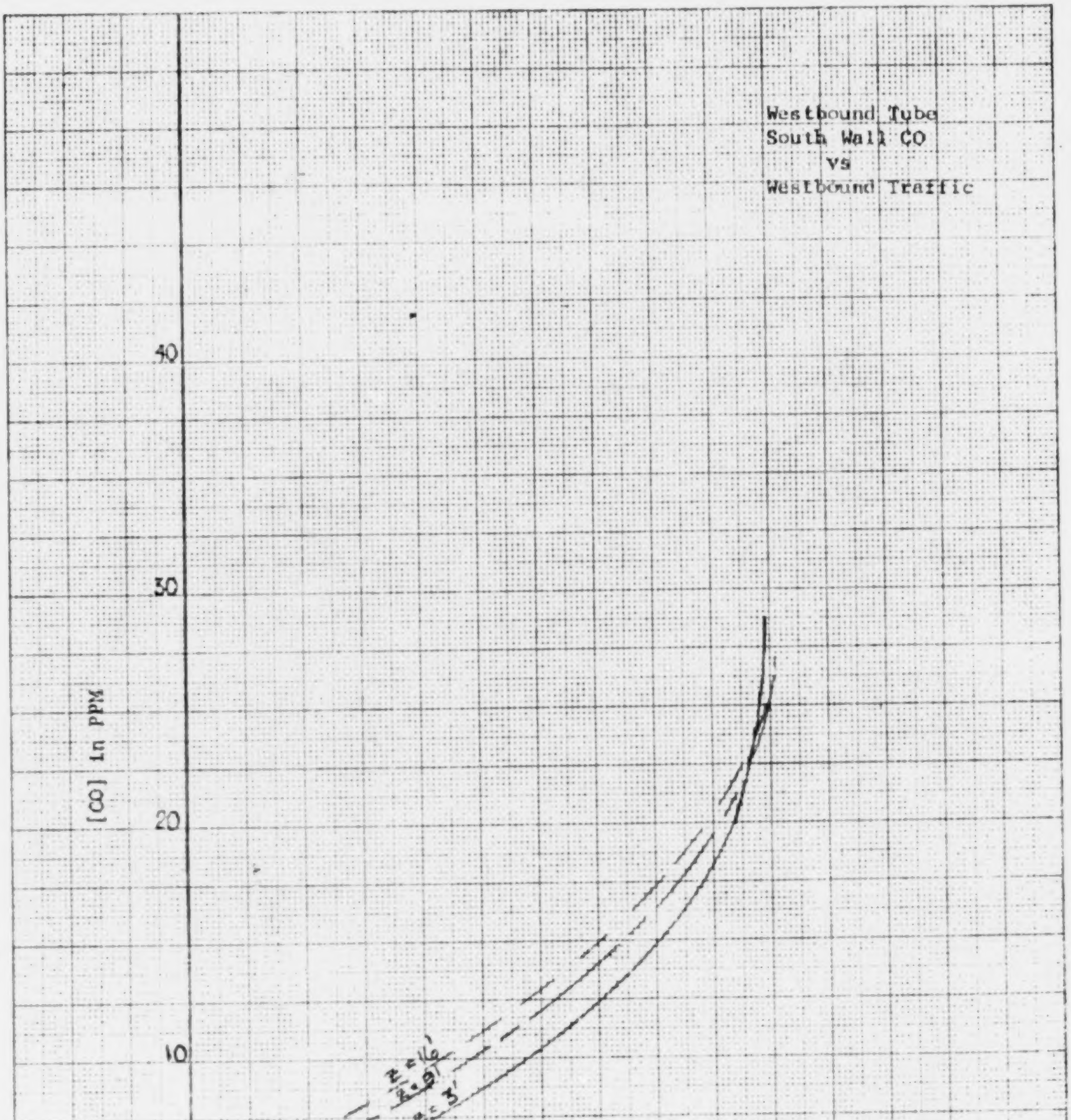


Figure 2.2-4 Profile of [CO] vs Traffic Flow Rate at Hugh J. Grant Circle

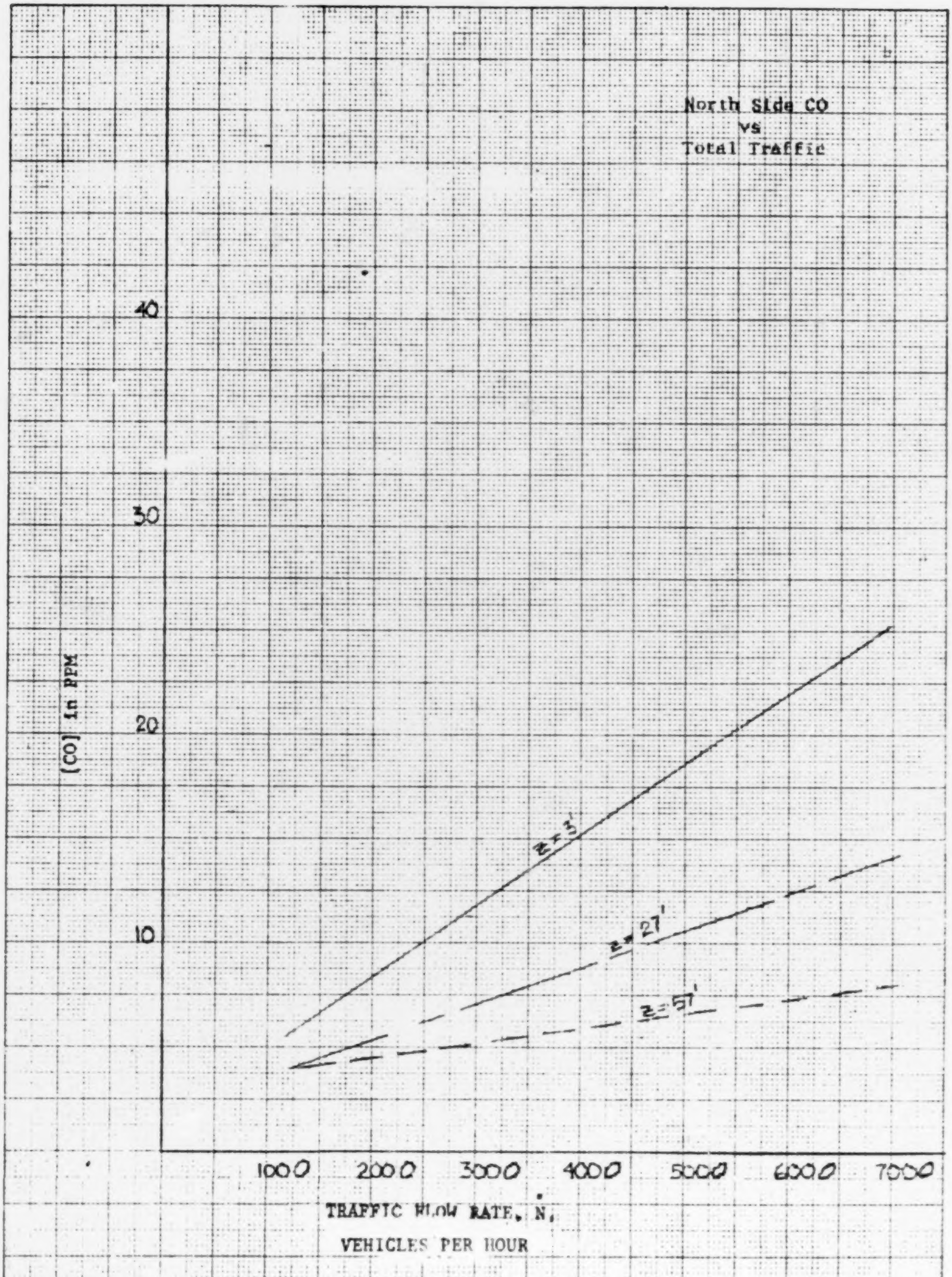


Figure 2.2-5 Profile of [CO] vs Traffic Flow Rate at CBE at Nelson & Jessup

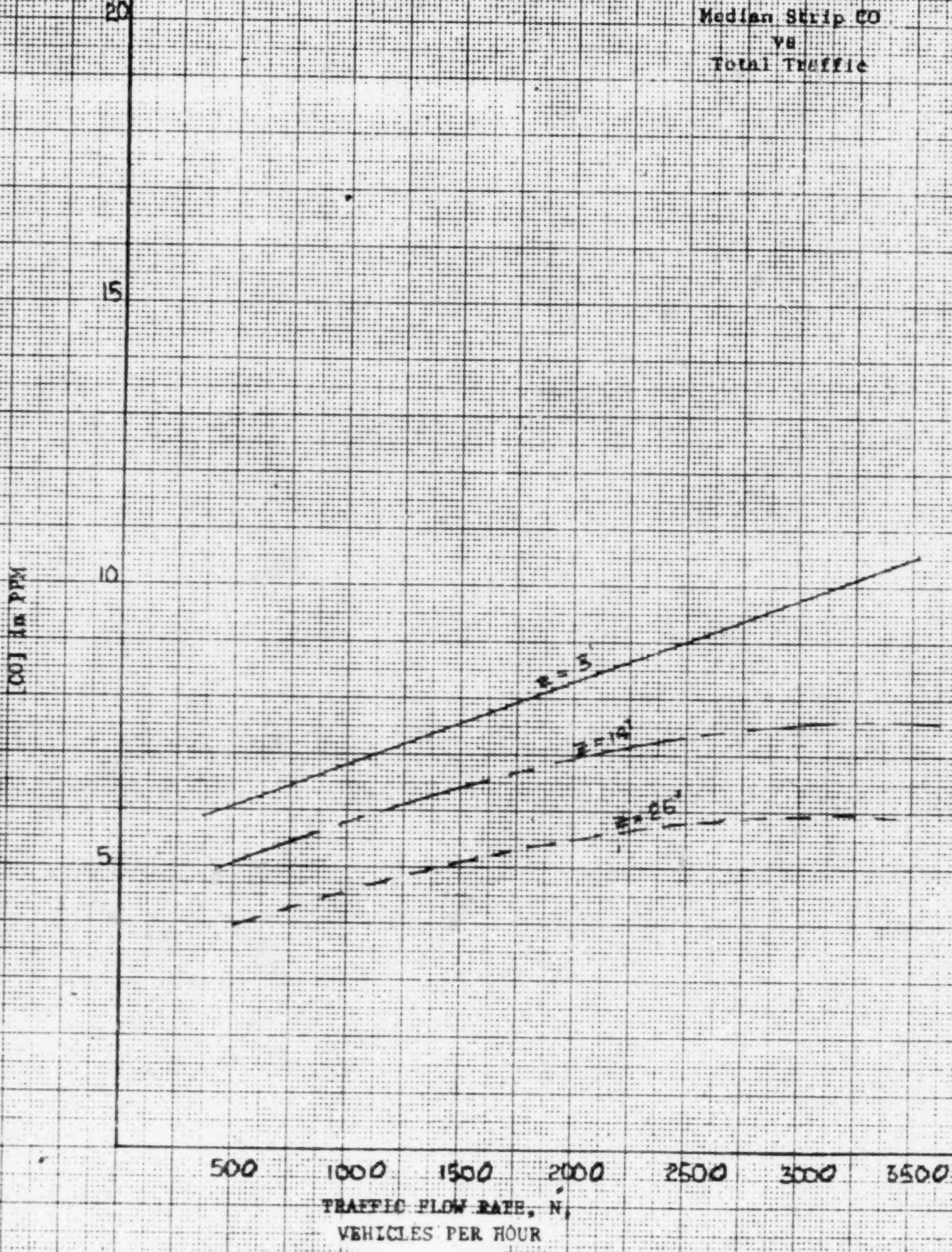


Figure 2.2-6 Profile of [CO] vs Traffic Flow Rate at Bruckner Expressway

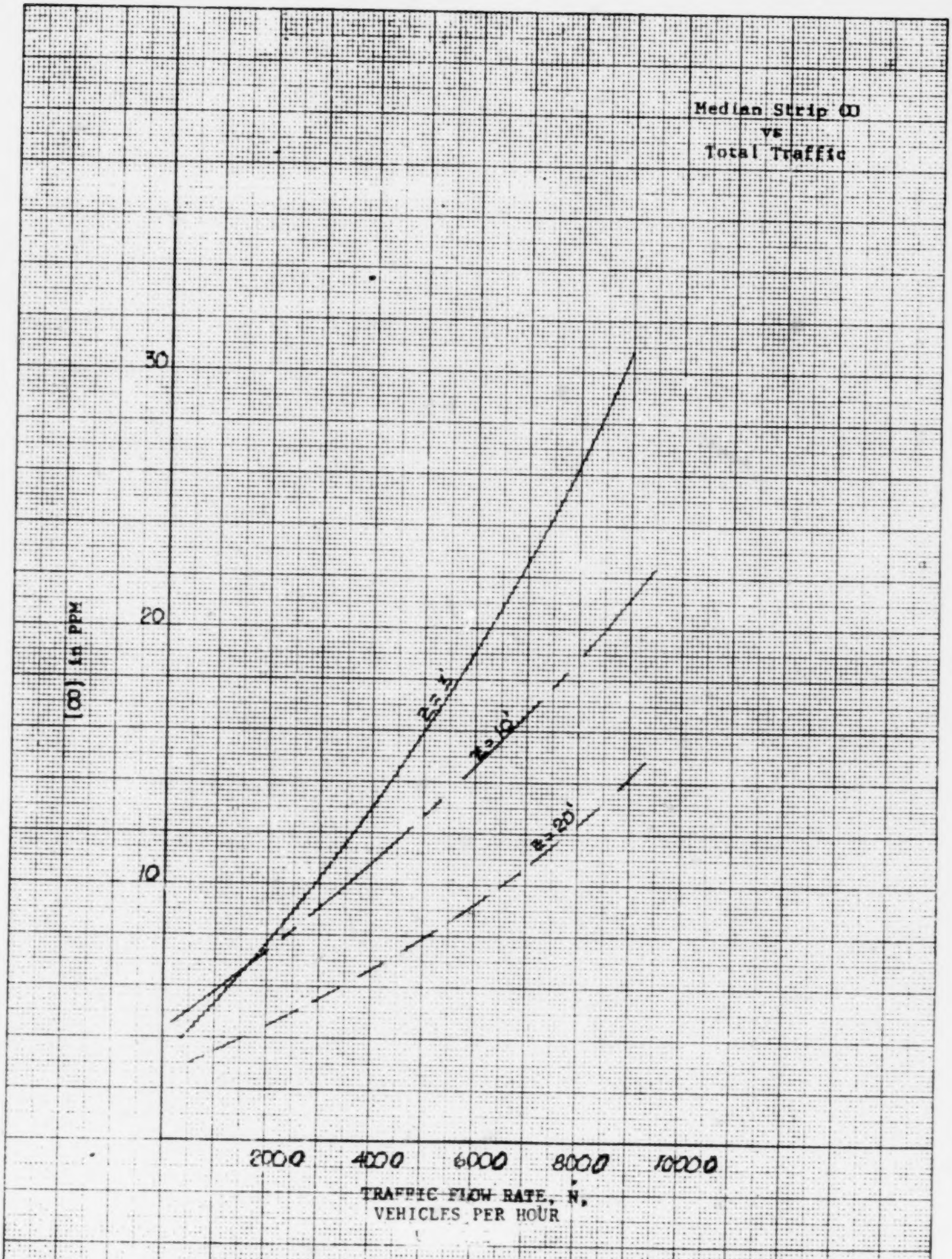


Figure 2.2-7 Profile of [CO] vs Traffic Flow Rate at Grand Central Parkway

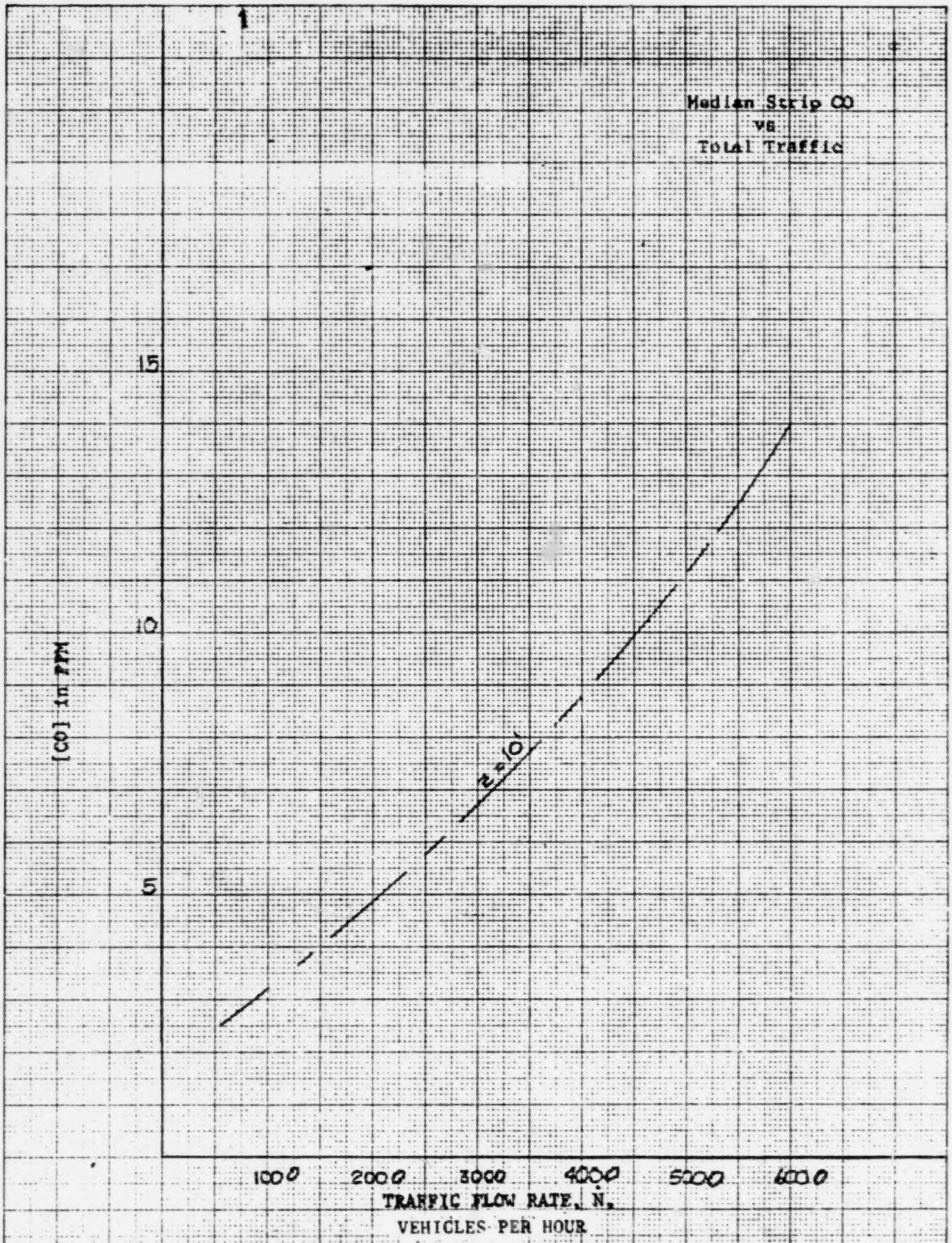


Figure 2.2-8 Profile of [CO] vs Traffic Flow Rate at Brooklyn Queens Expy.
(Park St. & Navy St.)

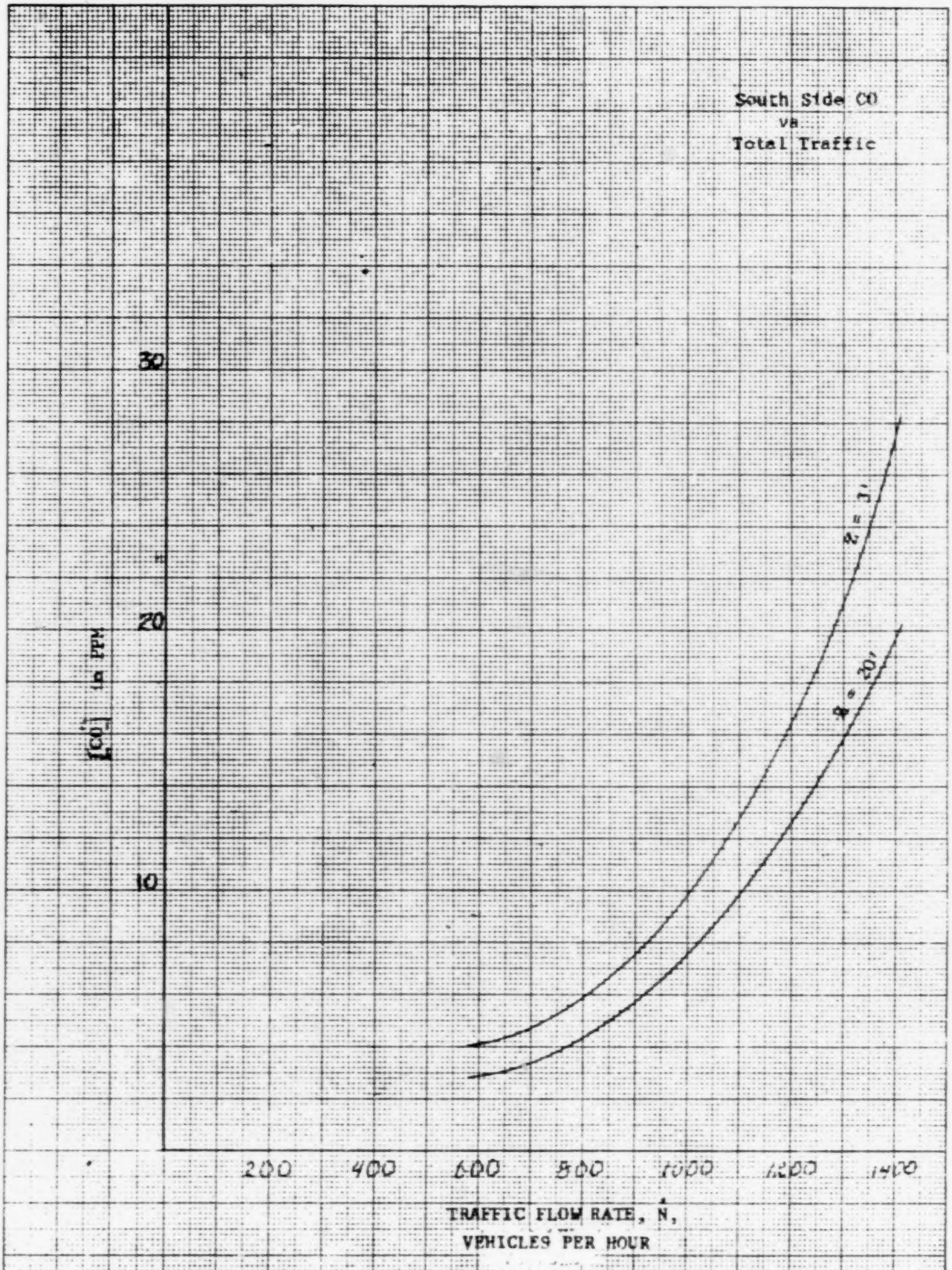


Figure 2.2-9 Profile of [CO] vs Traffic Flow Rate at Canal Street

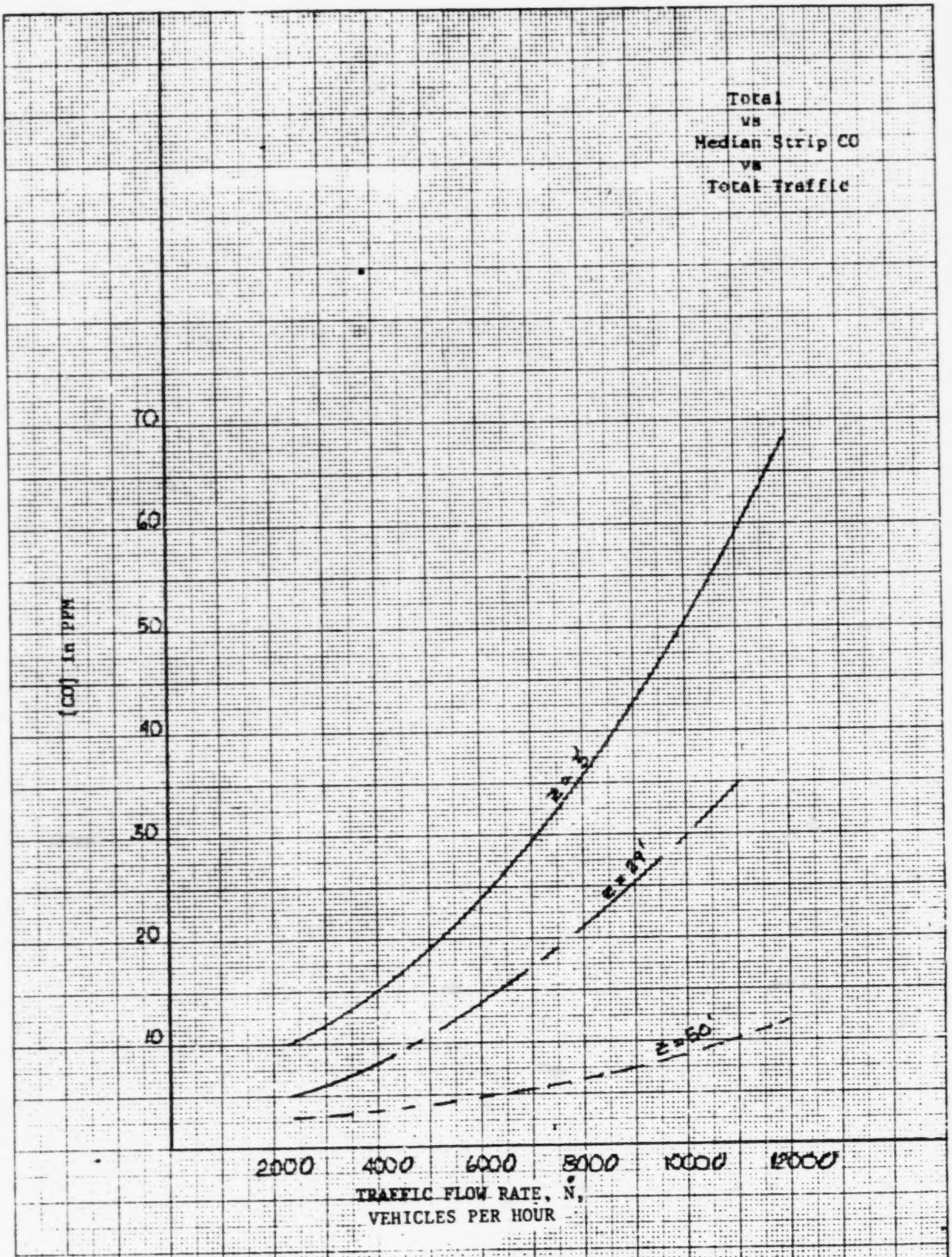


Figure 2.2-10 Profile of [CO] vs Traffic Flow Rate at George Washington Bridge

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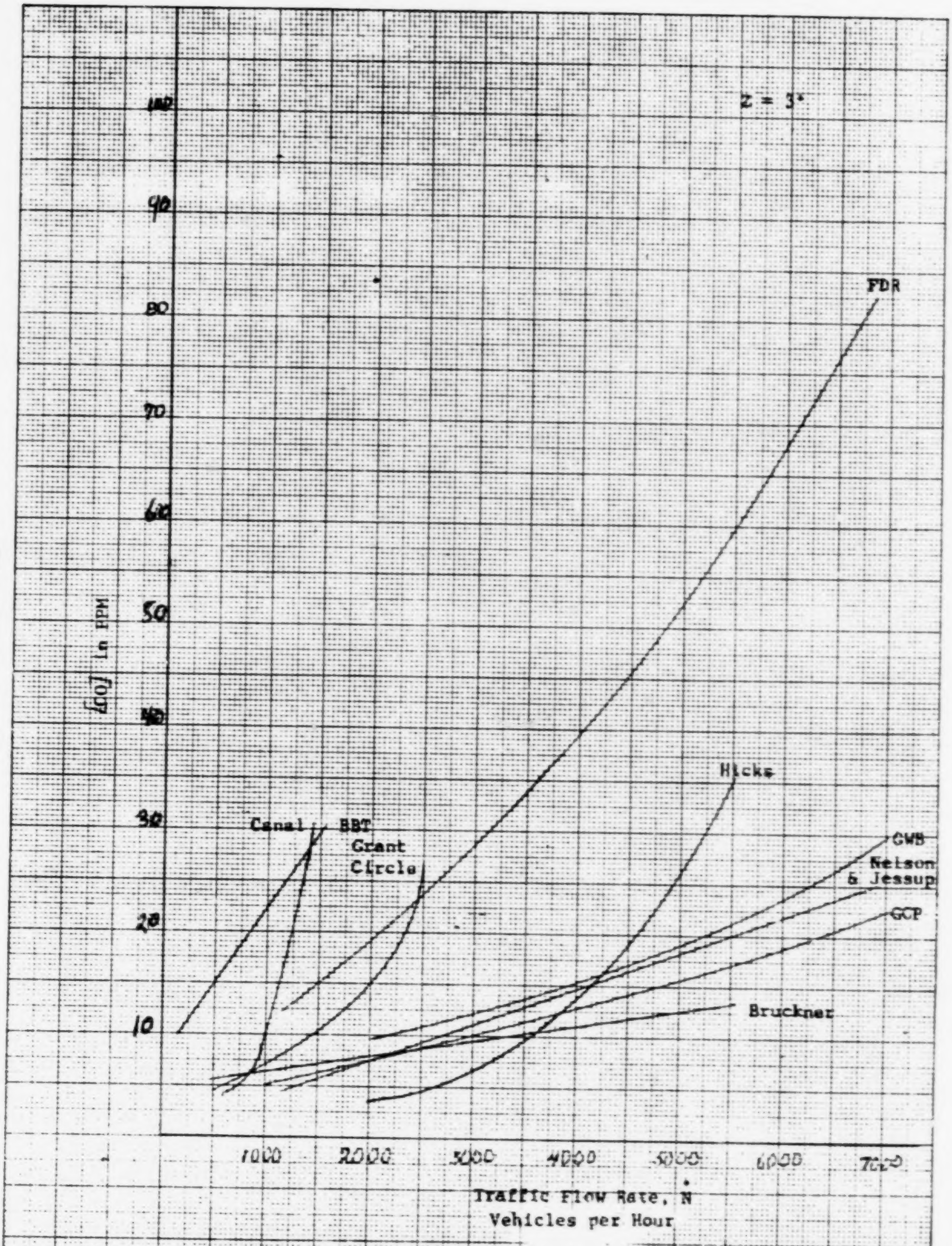

Figure 2.2-11 [CO] vs Traffic Flow Rate

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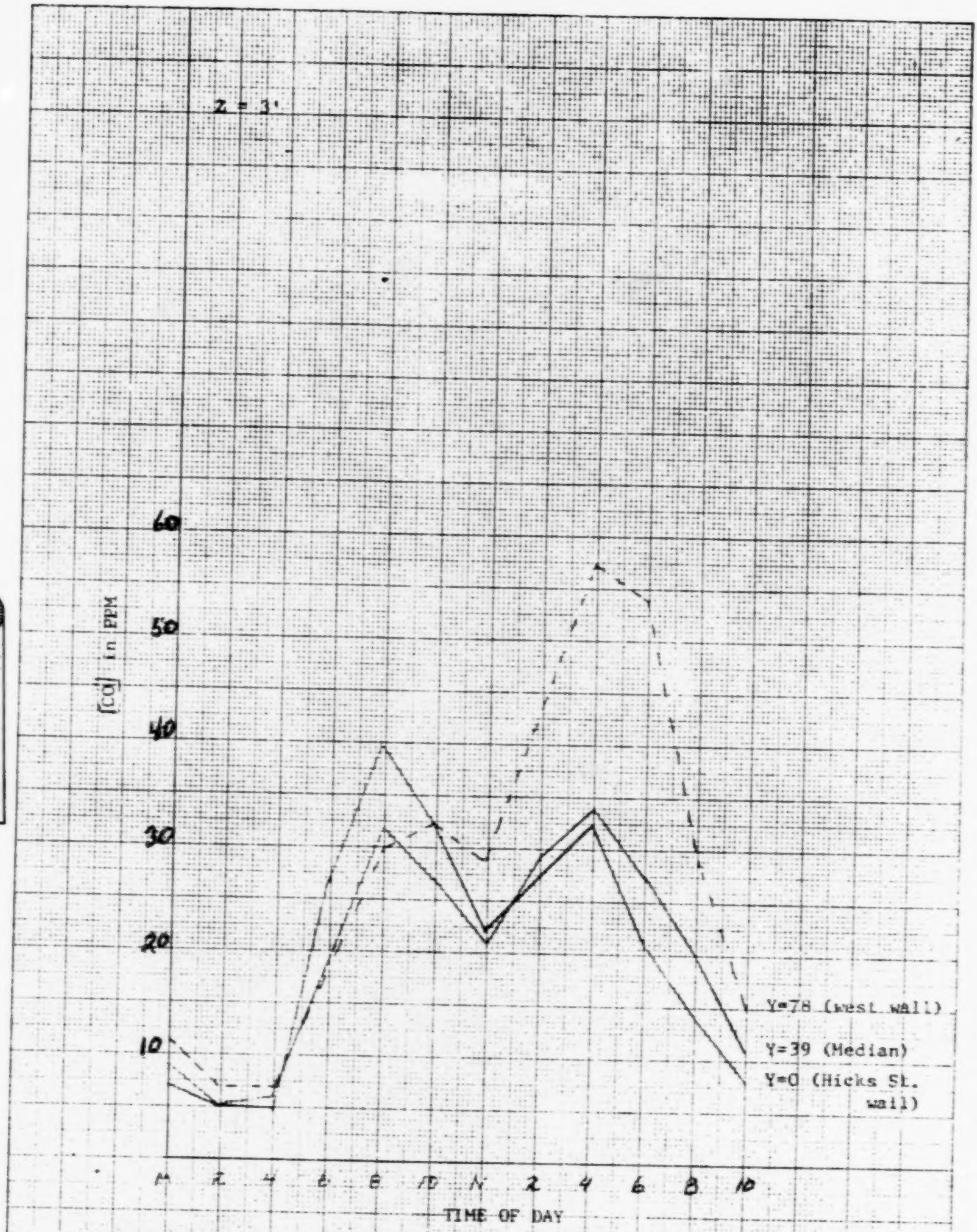


Figure 2.2-12 Average Weekday Diurnal CO at three points across Brooklyn Queens Expressway at Hicks Street

2.3 Site Ranking by Air Pollution Severity

This sub-section contains a comparison of monitored concentrations with EPA standards in 2.3.1, Vehicular Pollution Factors in 2.3.2 and Site Ranking by Concentration in Breathing Zone of Nearest Receptor in 2.3.3.

2.3.1 Comparison with Standards

The ten sites evaluated were examined from the viewpoint of the National Air Quality Standards which have been designed to protect public health and welfare. These standards are more directly applied to those areas where human health of the general public would most likely be affected; namely, dwellings, parks, sidewalks, etc. instead of on the actual roadway, inside tunnels and on shoulders of roadways. These latter areas could have health effects on automobile drivers, toll attendants, and maintenance men.

Table 2.3-1 presents the salient data obtained at the ten sites. Besides the obvious result that the maximum concentration was found directly over the roadway the following conclusions are drawn in light of the data obtained during the study.

1. Receptor sites adjacent to two of the test roadways, as shown in Column 6, were found to exceed the National Air Quality Standards for carbon monoxide* (9 ppm-maximum 8 hour concentration).
    a. Covered on top - open at side site, Figure 2.1-3A (Sutton Place over F.D.R. Drive). The closest ground level receptor site was in a nearby park. In addition, carbon monoxide measurements were made inside and outside a fifth floor apartment.
    b. Short tunnel site Figure 2.1-2B - Cross Bronx Expressway at Hugh J. Grant Circle. The closest receptor site was in a park 30 feet above the roadway.
2. Two sites, as shown in column 10, were found to exceed the National Air Quality Standards for particulates (260 micrograms/M^3 - maximum 24 hours).
    a. Short tunnel site, Figure 2.1-2B on Cross Bronx Expressway at Hugh J. Grant Circle.
    b. Deep cut site, Figure 2.1-1B on Cross Bronx Expressway at Nelson and Jessup Avenues.
3. At a distance of 3' off the roadway, all sites (column 7) exceeded the National Air Quality Standards for carbon monoxide except the viaduct and grade road sites.

---

* Hourly data averaged over a minimum of 14 days.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Site	Direction	Vehicular Pollution Factor (Φ) (PPM-hr.)/(veh.) x 10^3	Dilution Volume X 10^{-6}	Regression Slope (PPM-hr.)/(veh.) x 10^3 Directional Traffic/Total Traffic	Maximum Hourly CO Concentration at Nearest Receptor (PPM)	Peak Hourly CO Concentration on Roadway (PPM)	Average Daily Hydro-Carbon Concentration (PPM)	Soiling Index (COHS/1000 Lineal ft.)	Particulate Concentration $(\mu g/M^3)$ Hi Vol.	Percentage of Particulate Site Less Than 1 μ	Average Peak Hourly Traffic Volume	Average Total Daily Traffic Volume	Average Daily Traffic Speed (MPH)
Covered-on-Top, Open on One Side Franklin D. Roosevelt Drive / Sutton Place	SB NB	21 21 6	.11 .11 .40	26 13 11 8 4	28	164	7.5	1.7	150-212	72	3370 3820	47,007 49,615	(35) (35)
Long Tunnel (Ventilated) (Brooklyn Battery Tunnel)	EB WB	Not Calculated	Not Calculated	30 20 20 10 5 (Blower)	Back - Ground	200	No Data Taken	No Data Taken	142-180	42-72	2500 2430	25,676 25,224	(25) (25)
Short Tunnel (Cross Bx. Expressway)	EB WB	" "	" "	16 14	26	200	6	1.6	137-327	No Data Taken	2860 2570	43,933 41,957	42 48
Deep Cut (Cross Bx. Expressway)	EB WB	2.4 4.8 8.4	7.5 3.8 2.1	3 1 1.8 3 2	8	71	4	2.3	88-352	70-72	3590 4010	58,096 60,027	49 47
Shallow Cut (Brooklyn-Queens Expressway)	NB SB	12.7 2.1 20.0	.15 .1		11	120	5	1.9	82-214	66-68	3430 2980	53,968 53,009	38 38
City Street (Canal St., NYC)	EB WB	19.8 22.6	2.1 1.9		17	64	14	1.0	183-232	No Data Taken	670 860	12,645 15,032	17 15
Grade Road (Bruckner Expressway)	NB SB	3.3 8.1 3.0	5.5 6.0	.6 .4 2 .9 .2	9	34	3.5	0.7	130-214	71	2550 2140	25,232 25,063	48 48
Viaduct (Brooklyn-Queens Expressway)	NB SB	1.8 5.2 .8	1.0 1.9	2 1.8 1.7	6	26	11	0.6	115-129	No Data Taken	3910 3750	56,448 51,780	38 38
Cantilever (Grand Central Parkway)	EB WB	6.5 3.6 4.8	3.8 5.0 3.7		15	42	9	1.1	67-232	75	6006 6120	56,935 52,911	46 44
Intermittent Span (Trans-Manhattan Expwy.)	EB WB	4.9 7.5 7.5	4.4 2.8 2.8	7.6 4.8 7.2	15	85	14	1.0	82-200	No Data Taken	6250 6140	87,588 87,688	37 37

52.1

XXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXX

52.2

52.3

Table 2.3-1 - Summary of Salient Data at Each Site

A

1	2	3	4	5	6
Site	Dir-ection	Vehicular Pollution Factor (Φ) (PPM-hr.)/(veh.) X 10^3	Dilution Volume X 10^{-6}	Regression Slope (PPM-hr.)/(veh.) X 10^3 Directional Traffic/Total Traffic	Maxi Hour Conc tion Near Rece (PPM
Covered-on-Top, Open on One Side Franklin D. Roosevelt Drive @ Sutton Place	SB NB	21 21 6	.11 .11 .40	26 13 11 8 4	28
Long Tunnel (Ventilated) (Brooklyn Battery Tunnel)	EB WB	Not Calculated	Not Calculated	30 20 20 10 5 (Blower)	Back Grou
Short Tunnel (Cross Bx. Expressway)	EB WB	" "	" "	16 14	26
Deep Cut (Cross Bx. Expressway)	EB WB	2.4 4.8 8.4	7.5 3.8 2.1	3 1 1.8 3 2	8
Shallow Cut (Brooklyn-Queens Expressway)	NB SB	12.7 2.1 20.0	.15 .1		11
City Street (Canal St., NYC)	EB WB	19.8 22.6	2.1 1.9		17
Grade Road (Bruckner Expressway)	NB SB	3.3 8.1 3.0	5.5 6.0	.6 .4 2 .9 .2	9
Viaduct (Brooklyn-Queens Expressway)	NB SB	1.8 5.2 .8	1.0 1.9	2 1.8 1.7	6
Cantilever (Grand Central Parkway)	EB WB	6.5 3.6 4.8	3.8 5.0 3.7		15
Intermittent Span (Trans-Manhattan Expwy.)	EB WB	4.9 7.5 7.5	4.4 2.8 2.8	7.6 4.8 7.2	15

B

mum ly CO entra- at est ptor)	7 Peak Hourly CO Concentration on Roadway (PPM)	8 Average Daily Hydro-Carbon Concentration (PPM)	9 Soiling Index (COHS/ 1000 Lineal ft.)	10 Particulate Concentration (μg /M^3) Hi Vol.	11 Percentage of Particulate Site Less Than 1μ	12 Average Peak Hourly Traffic Volume	13 Average Total Daily Traffic Volume	14 Average Daily Traffic Speed (MPH)
	164	7.5	1.7	150-212	72	3370 3820	47,007 49,615	(35) (35)
- nd	200	No Data Taken	No Data Taken	142-180	42-72	2500 2430	25,676 25,224	(25) (25)
	200	6	1.6	137-327	No Data Taken	2860 2570	43,933 41,957	42 48
	71	4	2.3	88-352	70-72	3590 4010	58,096 60,027	49 47
	120	5	1.9	82-214	66-68	3430 2980	53,968 53,009	38 38
	64	14	1.0	183-232	No Data Taken	670 860	12,645 15,032	17 15
	34	3.5	0.7	130-214	71	2550 2140	29,232 25,043	48 48
	26	11	0.6	115-129	No Data Taken	3910 3750	56,448 51,780	38 38
	42	9	1.1	67-232	75	6000 6120	56,934 52,911	46 44
	85	14	1.0	82-200	No Data Taken	6250 6140	87,588 87,688	39 37

52.2

52.3

Table 2.3-1 - Summary of Salient Data at Each Site

2.3.2 Vehicular Pollution Factor

Eight of the ten sites were examined on the basis of the vehicular pollution factor*, as shown in column 3, Table 2.3-1. When the vehicular pollution factor, ϕ computed over all sites is plotted against the average traffic speed for all sites a linear relation results, as shown in Figure 2.3-1. Thus traffic speed seems to be the dominating influence on vehicular induced turbulence, since ϕ is defined at the exhaust plane level (3' off the roadway).

At the exhaust plane, vehicular speed is far more significant than the local meteorological effects. The peak hourly CO concentrations on the roadways (column 7 of Table 2.3-1) all occur at the exhaust plane level during rush hours when vehicle speed is well below the daily average. The obvious conclusion to be drawn by urban transportation planners from the data presented in Figure 2.3-1 is that an express roadway moving at higher average traffic velocities can accommodate more cars and produce lower carbon monoxide concentrations than a clogged city street. This result is a consequence of higher vehicular efficiency, lower emission of pollutant per travel distance and vehicular induced turbulence at the higher speeds. The linear relationship shown in Figure 2.3-1 between traffic speed and vehicular pollution is one of the important discoveries of this study. This is probably due to the quantity of data and the close proximity of the sampling probes to the roadway.

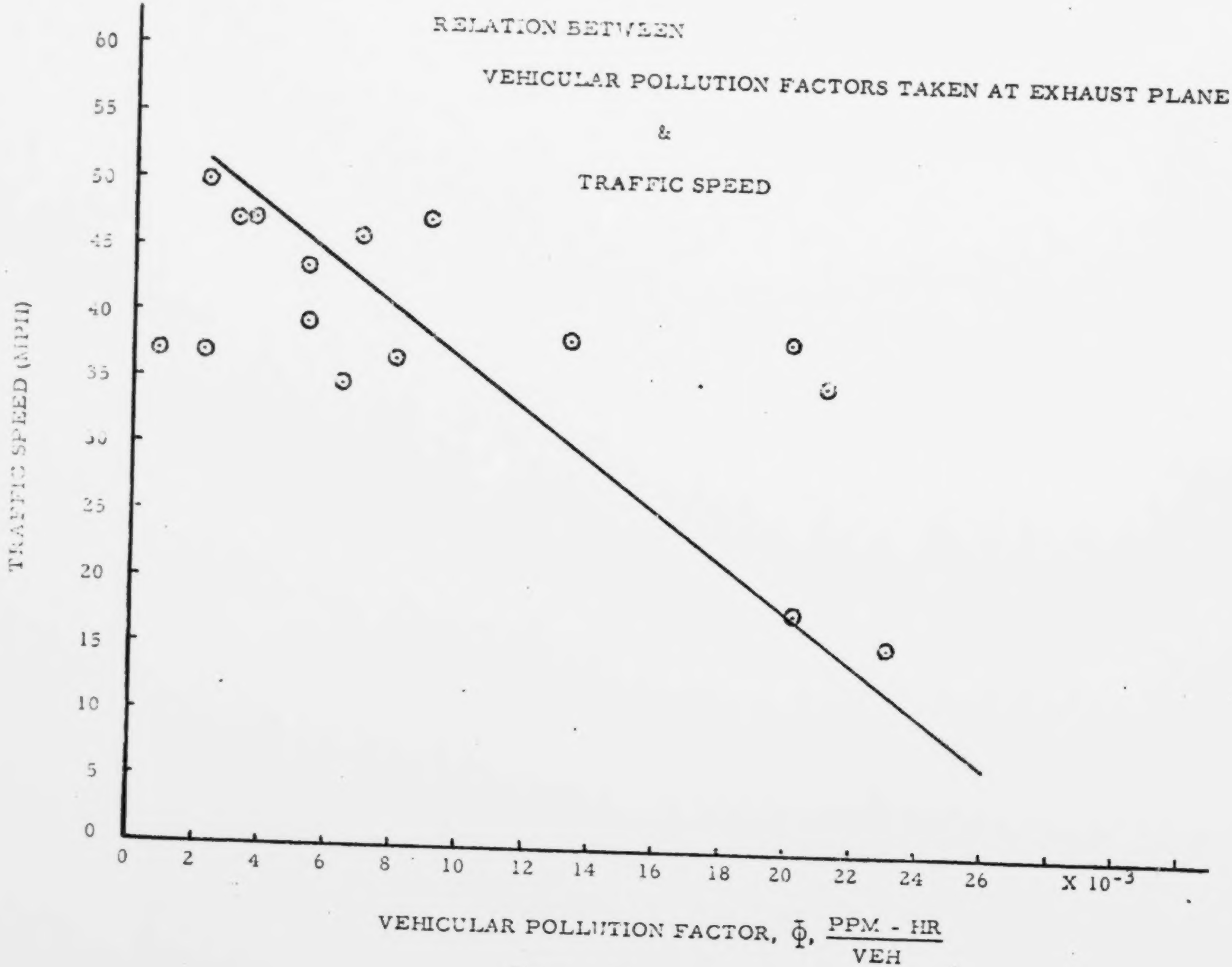
When the vehicular pollution factor is compared on the basis of constant traffic volume, the influence of site configuration is seen. The average daily total traffic speed at 3 sites, i.e., Hicks Street, Park & Navy and George Washington Bridge Plaza, was 38 mph. The total vehicular pollution factor is lowest for the viaduct site and highest for the shallow cut site. Thus, the more open the site, the lower the pollution at the roadway.

2.3.3 Ranking by Concentration in Breathing Zone of Nearest Receptor

The breathing zone concentration of the nearest receptor is another method by which the various sites may be ranked. Table 2.3-2 lists the maximum averaged hourly carbon monoxide concentration at the nearest receptor location, the linear distance from the roadway to the receptor location and the total number of days over which the data was averaged. As expected, those receptor locations that are the closest to the roadway yield the highest values, with the exception of the viaduct site where the ventilation was particularly good and the city street site where the traffic volume was small.

* Vehicular pollution factor, ϕ , $\left[\frac{\text{(ppm-hr)}}{\text{vehicle}}\right]$ is the hourly average concentration produced per vehicle at the exhaust plane, corrected for cross-roadway diffusion as explained in Section 3.3. Thus the factor is equivalent to an emission rate.

** The viaduct site was surrounded on one side by a park 2600 ft. wide on the one side and a playground apartment building courtyard 350 ft. away on the other side.



RELATION BETWEEN

VEHICULAR POLLUTION FACTORS TAKEN AT EXHAUST PLANE

&

TRAFFIC SPEED

Figure 2.3-1

Site	Maximum Averaged Hourly CO Concentration at Receptor Location (PPM)	Hour	Shortest Distance from Roadway to Receptor Location (Feet)	Number of Days over which Data Was Averaged
Covered on top Open at Side	28	0900-1000	20	11
Shallow Cut	11	1600-1700	62	13
Short Tunnel	26	1500-1600	30	12
Deep Cut	8	1700-1800	82	11
Grade Road	9	0700-0800 1700-1800	98	11
Cantilever	15	0700-0800	30	11
Viaduct	6	1700-1800	10*	13
City Street	17	1700-1800	6	11
Intermittent Span	15	1700-1800	45	8

* Nearest Receptor Location directly under Viaduct

Table 2.3-2

Maximum Hourly CO Concentration at Nearest Receptor

Rigorous comparisons are difficult since both traffic speed and volume flow rates vary from site to site. However, using the breathing zone of the nearest receptor, the ranking and the distances between receptor and roadway and the sites is presented in Table 2.3-3. It is interesting that the higher carbon monoxide concentrations at the receptor are associated with the two sites which are covered. Also, it is these sites which exceeded the Federal Air Quality Standards. This suggests that caution in locating parks and air rights structures in the immediate vicinity of covered sites should be observed.

Site	Maximum Averaged Hourly CO Concentration at Receptor in PPM	Distance Between Nearest Receptor & Roadway in feet
Viaduct	6	10
Deep Cut	8	82
Grade Road	9	98
Shallow Cut	11	62
Cantilever	15	30
Intermittent Span	15	45
City Street	17	6
Short Tunnel	26	30
Covered on top- Open at side	28	20

Table 2.3-3 Ranking of Sites by Breathing Zone of the Nearest Receptor

2.4 Indoor-Outdoor Relationships

Figures 2.4-1 through 2.4-5 show the hourly mean values for carbon monoxide at each of five sites where both indoor and outdoor concentrations were monitored.

In general the outdoor concentrations tend to be higher but only seldom does this difference exceed 4 PPM. The graphs show that, as the outdoor values increase, the indoor ones also go up but with a time lag of up to two hours. This is also true as the outdoor concentrations decrease although sometimes, if ventilation of the building is not good, the inside levels will remain elevated above the outside values for longer periods of time. Time of year, because of open windows and doors, will affect these ventilation rates.

Both indoor and outdoor concentrations follow each other closely and have the same general shape. In the case of air rights structures, the indoor weekend levels were generally higher than outside reflecting increased cooking and household activities. At the George Washington Bridge Apartments the weekday indoor levels were mostly higher than those outside at the 3rd floor level. This could be a result of the flow of air in the building from the ground floor to the roof. Weekday values at the 9th floor level show higher than the 3rd floor and this results both from the upward air flow plus the addition of carbon monoxide from apartment activities on the intervening floors.

Three weekday and two weekend concentrations at four sites for an eight-hour period exceeded the National Primary Ambient Air Quality Standard of the Federal Government. At Canal Street, the Brooklyn Queens Expressway at Hicks Street and Sutton Place the levels were greater during weekdays indoors than the 9 PPM allowed. At Sutton Place and Grand Central Parkway at Parsons Boulevard, the weekend levels also exceeded this value. As shown on the graphs, these concentrations are dependent upon outside levels.

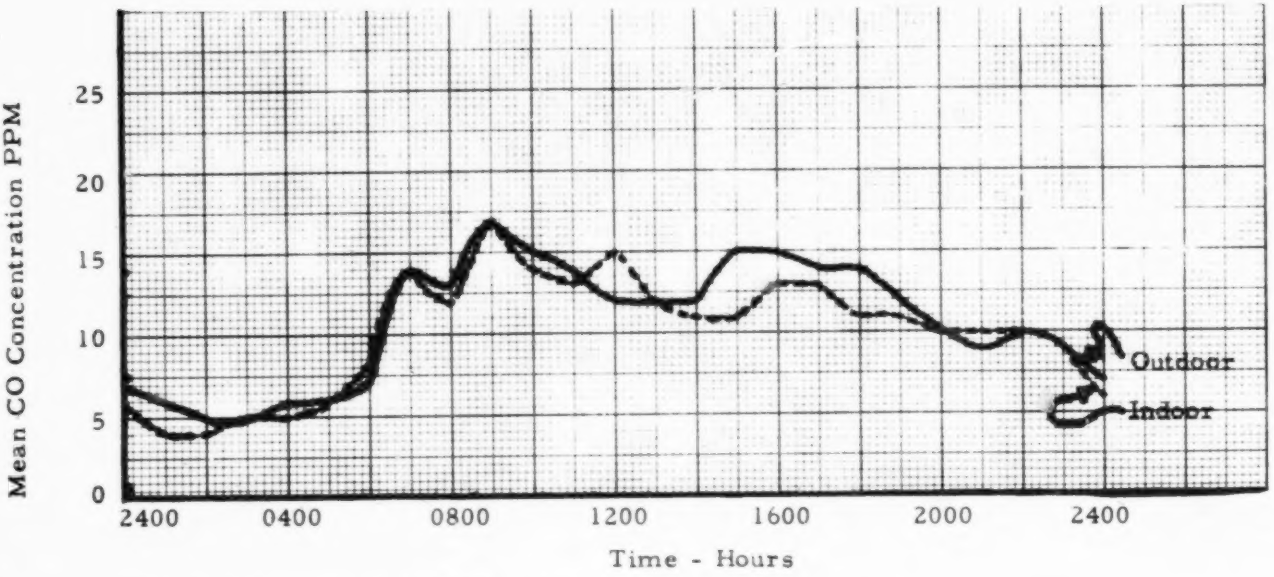


Fig. 2.4-1A Weekday Indoor/Outdoor CO Concentration

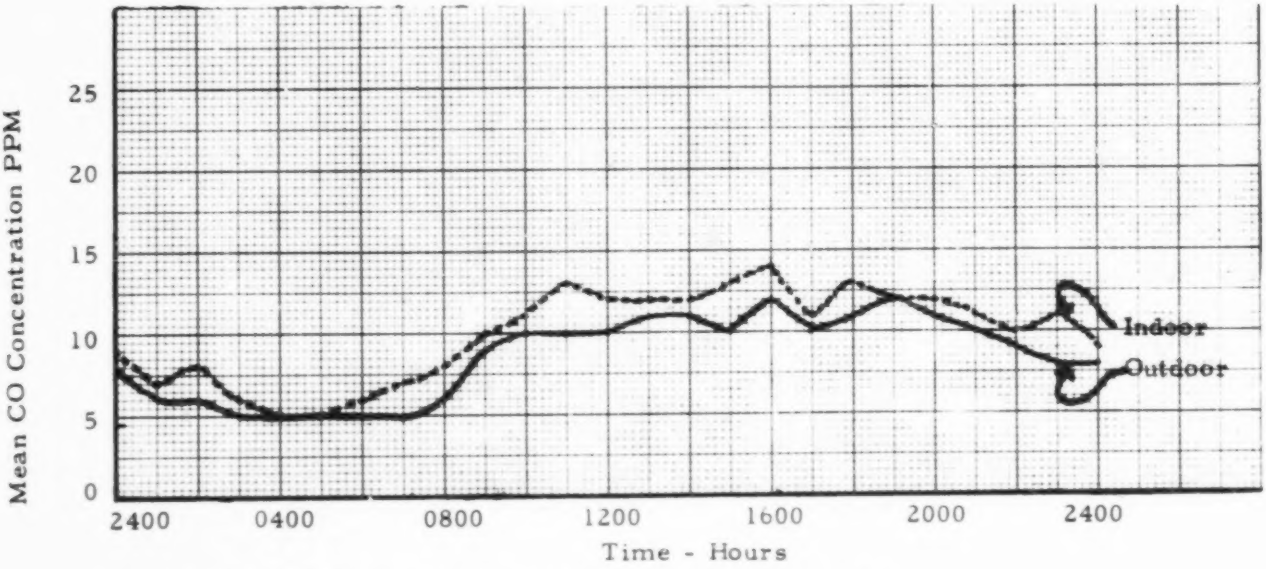


Fig. 2.4-1B Weekend Indoor/Outdoor CO Concentration

Fig. 2.4-1 Diurnal Indoor & Outdoor Carbon Monoxide Concentrations in Air Rights Building at Sutton Place

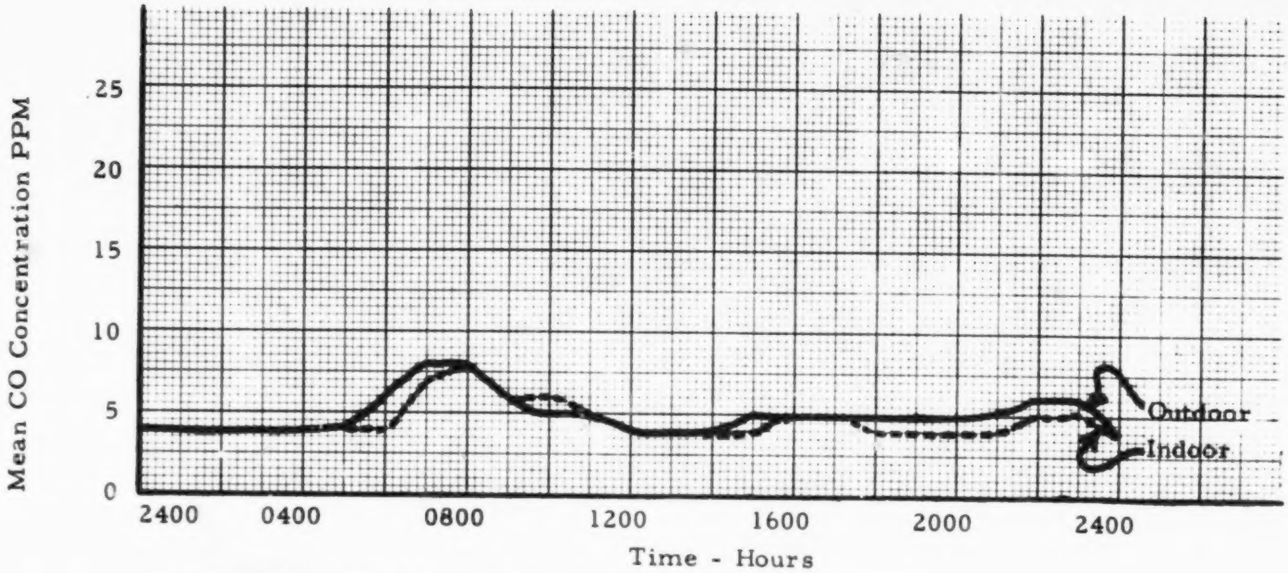


Fig. 2.4-2A **Weekday Indoor/Outdoor CO Concentration**

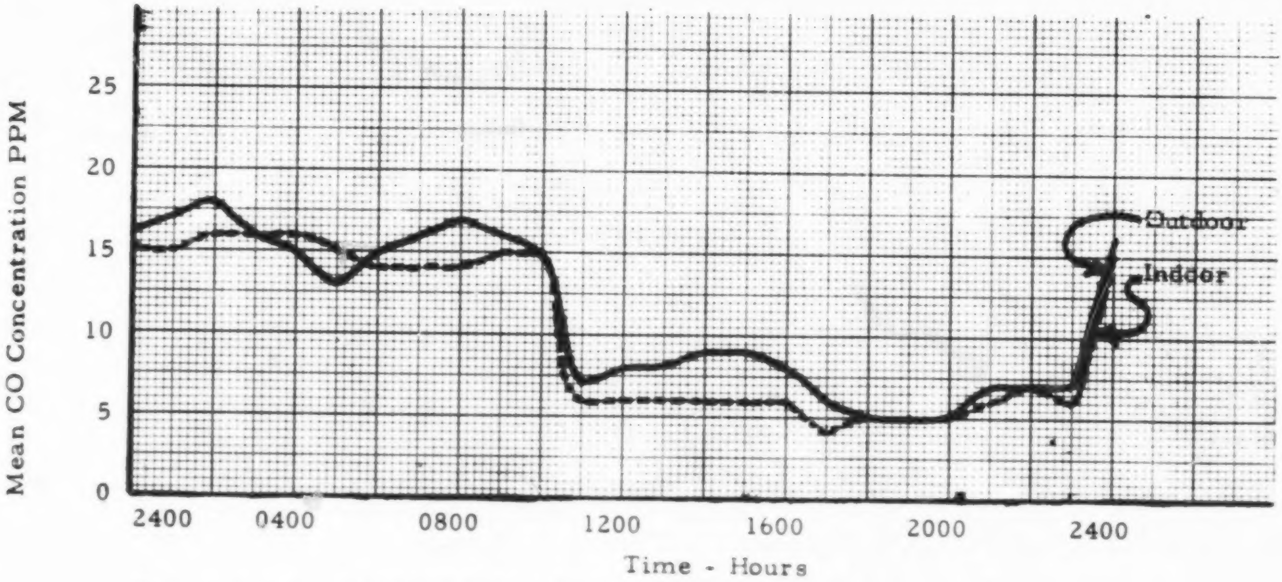


Fig. 2.4-2B Weekend Indoor/Outdoor CO Concentration

Fig. 2.4-2 Diurnal Indoor & Outdoor Carbon Monoxide Concentrations Near a Double Cantilever Covered Open Top Middle at Grand Central Parkway at Parsons Boulevard

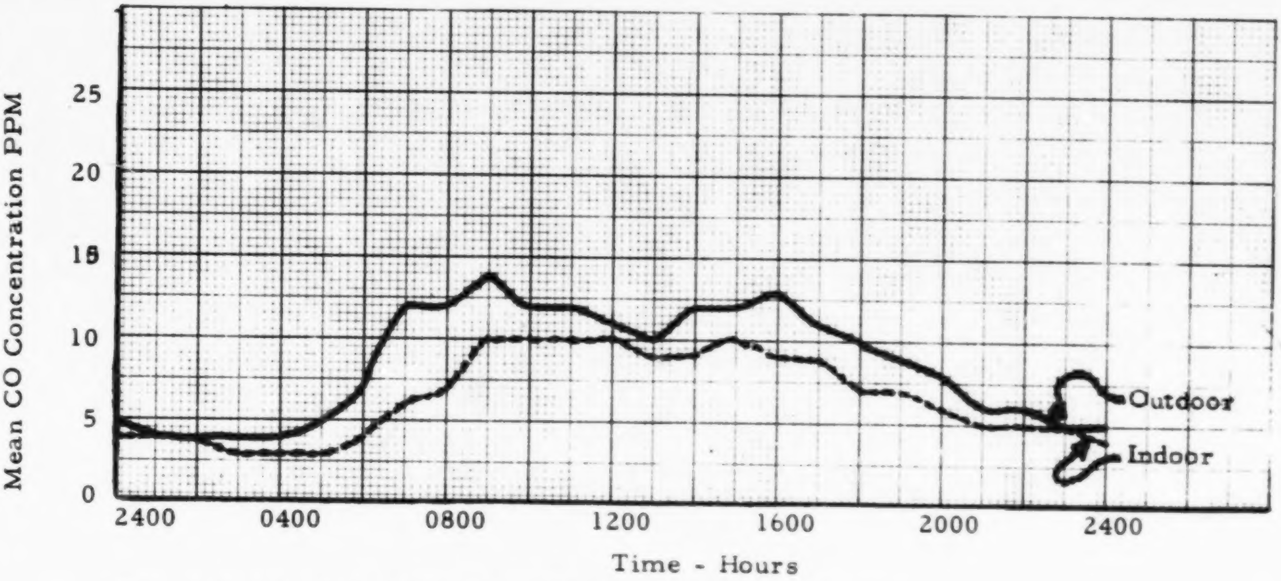


Fig. 2.4-3A Weekday Indoor/Outdoor CO Concentration

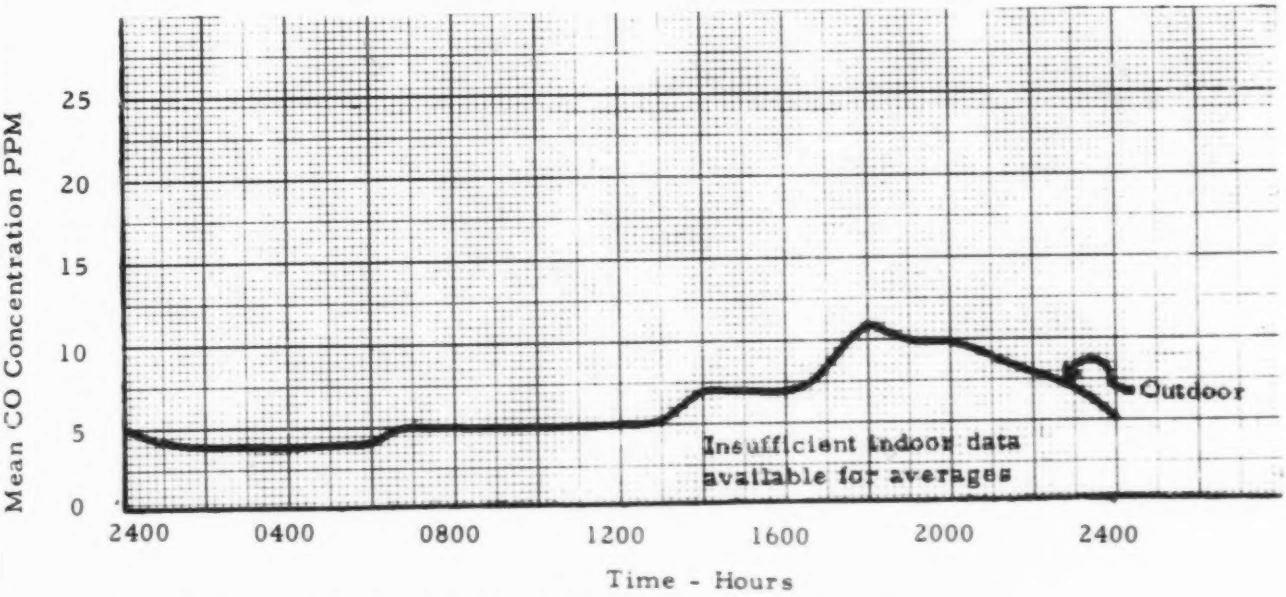


Fig. 2.4-3B Weekend Indoor/Outdoor CO Concentration

Fig. 2.4-3 Diurnal Indoor & Outdoor Carbon Monoxide Concentrations Near an Open Cut on Brooklyn-Queens Expressway at Hicks Street (in a School)

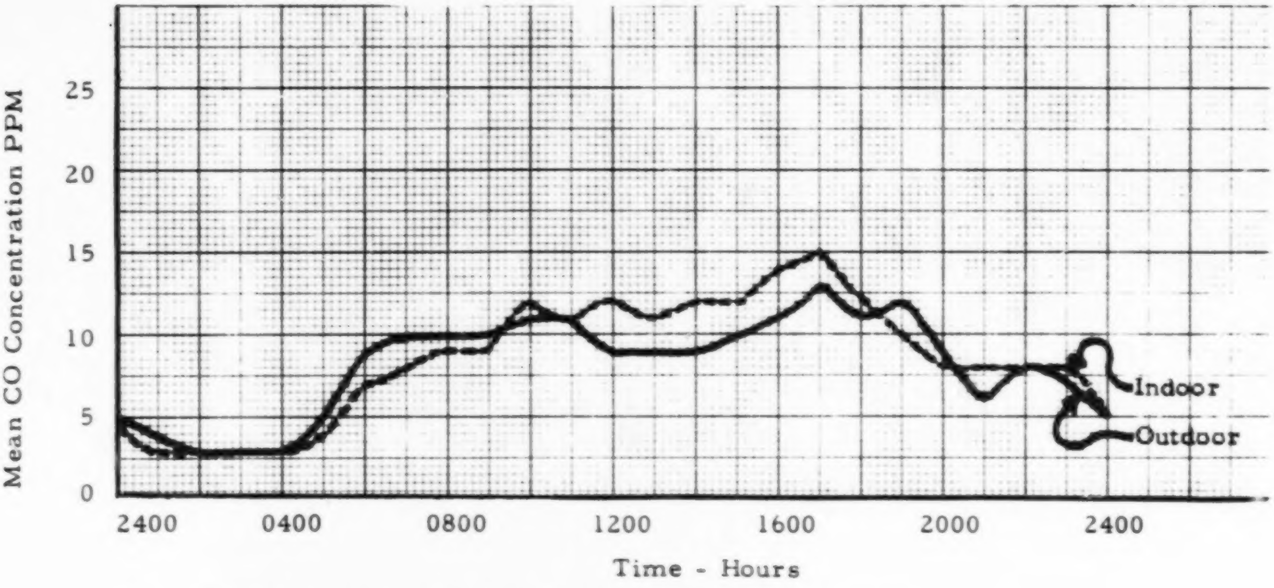


Fig. 2.4-4A Weekday Indoor/Outdoor CO Concentration

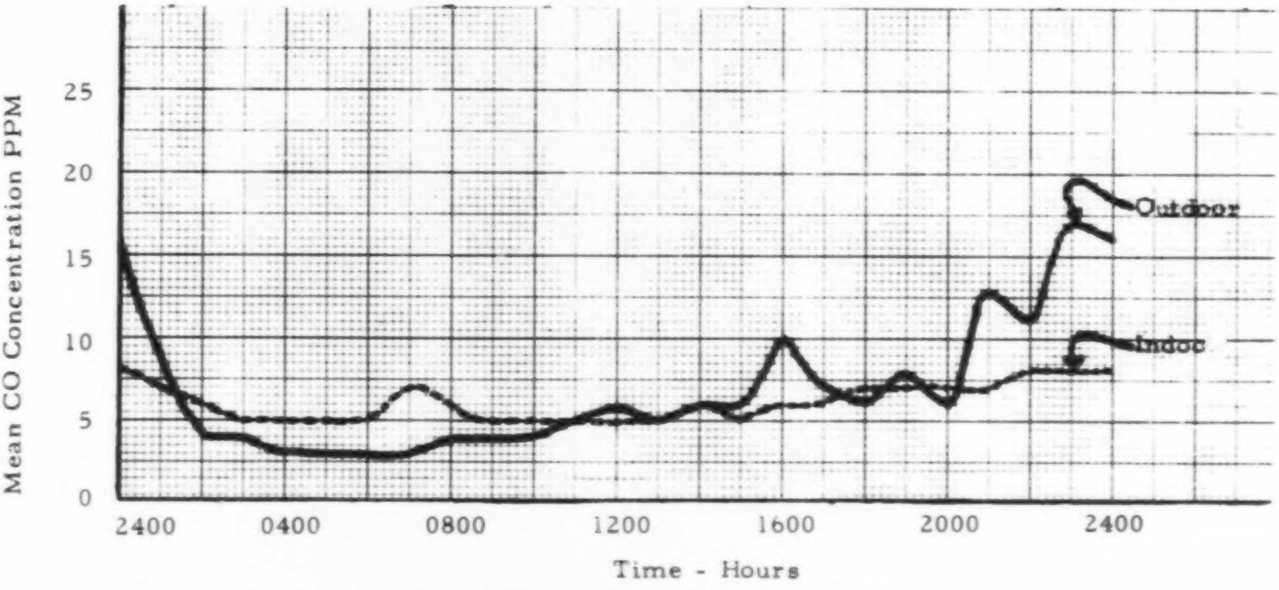


Fig. 2.4-4B Weekend Indoor/Outdoor CO Concentration

Fig. 2.4-4 Diurnal Indoor & Outdoor Carbon Monoxide Concentrations on Canal Street (in a Building)

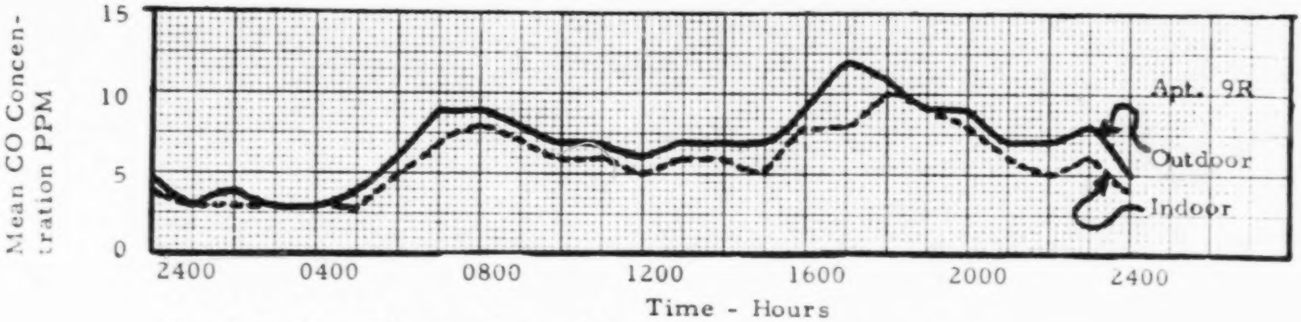


Fig. 2.4-5A Weekday Indoor/Outdoor CO Concentration

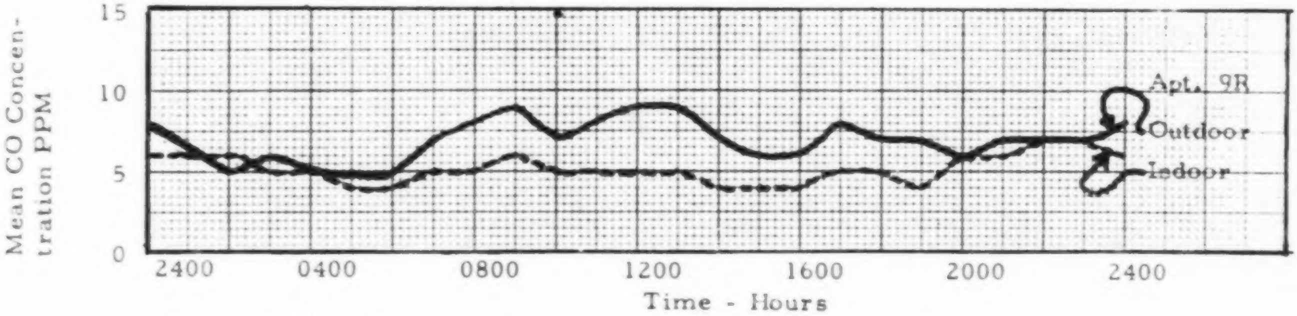


Fig. 2.4-5B Weekend Indoor/Outdoor CO Concentration

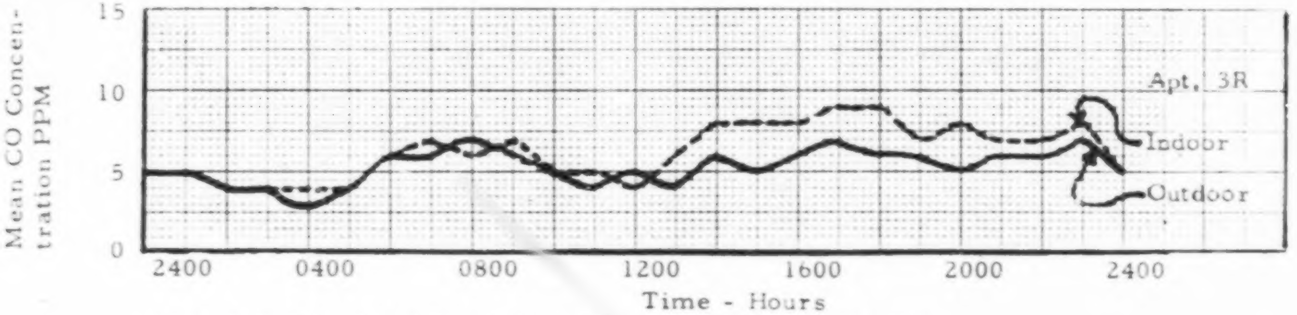


Fig. 2.4-5C Weekday Indoor/Outdoor CO Concentration

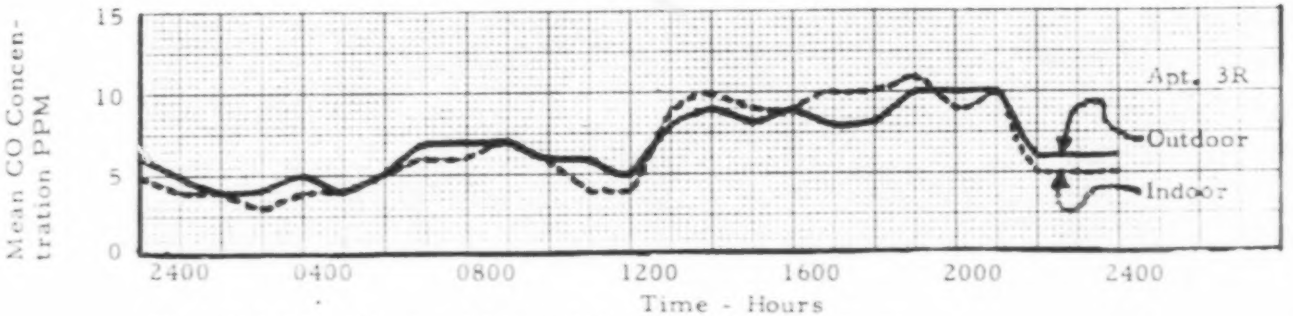


Fig. 2.4-5D Weekend Indoor/Outdoor CO Concentration

Fig. 2.4-5 Diurnal Indoor & Outdoor Carbon Monoxide Concentrations in an Air Rights Building Over the Trans-Manhattan Expressway Near the George Washington Bridge Plaza

2.5 Recommendations for Future Research

This section consists of three parts. Recommendations for further measurements of traffic, air quality and meteorology factors are given in 2.5.1. Recommendations concerning model development based on data from this study and on further measurements are in Section 2.5.2. Recommendations for health effects study are given in Section 2.5.3.

2.5.1 Recommendations for Further Measurements

Two fundamental questions in the development of good predictive models for traffic generated carbon monoxide are:

- The form of the law of decay of concentration with distance from the source
- The role of traffic generated turbulence in providing a diffusive mechanism for the transport of the traffic generated carbon monoxide

Analysis of the data gathered in the course of this study strongly suggests that the vertical decay with height above the source plane is exponential in character when the top of the site is open to ventilation. The situation is not as clear in the case of tunnels. The law of decay of concentration with horizontal distance from the source is also not entirely clear. With the exception of the Sutton Place site, there were not generally enough probes at a given height to obtain a good estimate of the shape of the horizontal concentration profile at that height. While it is true that the suspicion exists that the horizontal profiles are Gaussian in shape, the need remains to verify that this is true. Because the concentration gradients are often quite small, they tend to be masked by instrument error. This makes it difficult to obtain good estimates of the shape of the concentration profiles, even with a larger number of probes, if absolute values of the concentration are taken at each point. Instead, the procedure that should be used is to obtain the difference concentration between each pair of probes employing a single long path infra-red instrument fitted with a floating reference cell to replace the fixed reference cell. The Intertech, URAS-2 instruments used in this study can employ floating reference cells marketed by the Intertech Corporation.

Indications of turbulence were obtained, at each of the sites in this study, by means of the Sigma Meters discussed in Section 3. However the need exists for a more direct measure of the quantities $u^{1}c^{1}$, $v^{1}c^{1}$ and $w^{1}c^{1}$ at each of the points at which a carbon monoxide probe is located. These quantities which define the turbulence at a given point over some averaging time have the following meaning.

$$\overline{u^1c^1} = \frac{1}{T}\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} u^1c^1\,dt$$

$$\overline{v^1c^1} = \frac{1}{T}\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} v^1c^1\,dt$$

$$\overline{w^1c^1} = \frac{1}{T}\int_{t-\frac{T}{2}}^{t+\frac{T}{2}} w^1c^1\,dt$$

where:

T = averaging time

c^1 = fluctuation of the concentration, C, about the mean value $\overline{c}$ at any instant during the averaging time

u^1, v^1, w^1 = fluctuation of the x, y, z components of wind, u, v, w, about the means $\overline{u}$, $\overline{v}$, $\overline{w}$ at any instant during the averaging time.

Since it can be shown that

$$\overline{u^1c^1} = \overline{uc} - \overline{u}\,\overline{c}$$

$$\overline{v^1c^1} = \overline{vc} - \overline{v}\,\overline{c}$$

$$\overline{w^1c^1} = \overline{wc} - \overline{w}\,\overline{c},$$

it is possible to determine these correlation functions directly at any point where a carbon monoxide probe and a device which determines wind speed, wind elevation and wind azimuth angles can be co-located. A simple, hybrid circuit, turbulence cross correlation computer has been designed at General Electric and could be built inexpensively. The solid state circuit elements are similar to those used in the Data Converter developed by G.E. for APCO in the Indoor/Outdoor Study. With such a device it would be possible to obtain; turbulence measurements for various averaging times; diurnal variation of turbulence; correlations of turbulence with traffic volume and speed, concentration gradient, wind speed and direction and other pertinent variables.

2.5.2 Recommendations for Further Model Development

The Superposition Model described briefly in Section 2.1.3 and in more detail in Section 3 has been reasonably successful in estimating traffic generated carbon monoxide concentrations. It is felt, however, that the model can be improved by modifying the assumed law of exponential decay with radial distance from the source. It is believed that if the decay law assumed exponential decay with height above the source and a gaussian decay horizontally, that predictive accuracy would be improved. Accordingly, it is recommended that such a modified Superposition model be exercised on the data gathered during this study.

Because the superposition model does not contain wind and turbulence terms explicitly, it is further recommended that a more theoretical model be pursued. The basic approach would consist of attempting a solution to the basic differential equation

$$\frac{\partial \bar{c}}{\partial t} = -\bar{u}\frac{\partial \bar{c}}{\partial x} - \bar{v}\frac{\partial \bar{c}}{\partial y} - \bar{w}\frac{\partial \bar{c}}{\partial z} - \frac{\partial}{\partial x}\left(\overline{u'c'}\right) - \frac{\partial}{\partial y}\left(\overline{v'c'}\right) - \frac{\partial}{\partial z}\left(\overline{u'c'}\right)$$

using the data gathered in the turbulence experiment recommended in Section 2.5.1.

Although the superposition model was applied to the two tunnel configurations, the air quality data suggests that tunnels do not show a continuous line source. Close to the ceiling exhaust fan ventilation and the "piston" effect of the vehicles in tunnels provide a controlled environment whereby the Vehicular Pollution Factor, Φ, can be evaluated more vigorously. Also in a tunnel environment, vehicular induced turbulence can be measured as a function of speed which will allow for better predictive techniques. This latter point is a key one since no speed data was taken in the tunnel and the speed data taken for the rest of the sites was sparse. It is recommended that a tunnel study be undertaken in which wind speed, wind turbulence, vehicular speed, vehicular volume, and vehicular mix be measured in order to develop a more adequate tunnel model, a better definition of vehicular induced turbulence, and a better definition of the Vehicular Pollution Factor, Φ.

Finally, the speed taken did not provide sufficient range to define the Vehicular Pollution Factor, Φ, for speed ranges above 50 mph and below 15 mph. There is also a range between 35 mph and 17 mph where the data is meager. Also, the strong linear correlation between Φ and vehicular speed has not been found by previous workers and it is recommended that further investigations be undertaken to determine the universality of this relation.

2.5.3 Recommendations for Health Effects Research

It is recommended that a medical team do a continuing follow-up study of the population residing near each of the sites in this urban expressway study. Special attention should be directed toward the tenants in the two air rights buildings.

3.1 Measurement Techniques

3.1.1 Overall Methodology

In order to monitor the various traffic-derived pollutants and wind parameters at the ten selected site configurations, a 30' aluminum van was equipped with a variety of air pollution measuring devices. This mobile laboratory provided the capability, as shown in Fig. 3.1-1, of sensing, measuring and recording carbon monoxide, hydrocarbons, and other related parameters. A New York State Department of Transportation Traffic trailer was used to obtain traffic measurements at the test sites. These measurements included daily traffic volumes, hourly vehicle counts, average speeds, and some indication to the mix ratio between trucks, buses and automobiles.

The GE Air Pollution Van and the New York State Traffic trailer were parked adjacent to the roadway at each site. Both trailers were supplied the necessary electrical power, from an external source, to operate all equipment used in this study.

In order to study the relationships between pollution levels, traffic patterns, and meteorological data, each parameter had to be simultaneously monitored and recorded for final data analysis. Various pollution levels and meteorological variables were continuously monitored at each site for an extended period of the time to insure that a sufficient amount of relevent data was obtained. Data was collected for several weeks at each site to obtain both weekday and weekend coverage.

A sampling technique was utilized that allowed for the largest number of point samplings to be made using the instruments available to systematically relate pollution measurements with all other variables. A total of sixteen possible probe locations at each site were monitored to obtain hourly CO and hydrocarbon concentration averages. The probe locations were divided into sets of eight probes each. Each set of eight probes was sampled alternately for a period of five minutes. In a hour, each probe location was monitored six times for a total of thirty minutes. Fig. 3.1-2 shows the flow diagram in the trailer for CO and hydrocarbon measurements.

Polyethylene tubing was directed from an intake manifold at the GE van to specified positions over the roadway. The probes were all positioned in a plane perpendicular to the roadway under evaluation to develop a two dimensional CO profile of the site. This mapping technique displayed CO contour concentrations as related to horizontal and vertical distances at the roadway. This profile, in conjunction with data on traffic and meteorological conditions recorded at the same time, gives valuable information as to vehicular emission concentrations/CO diffusion characteristics, wind effects, and calibration data for formation of theoretical mathematical site models which can define similar site situations without actual investigation.

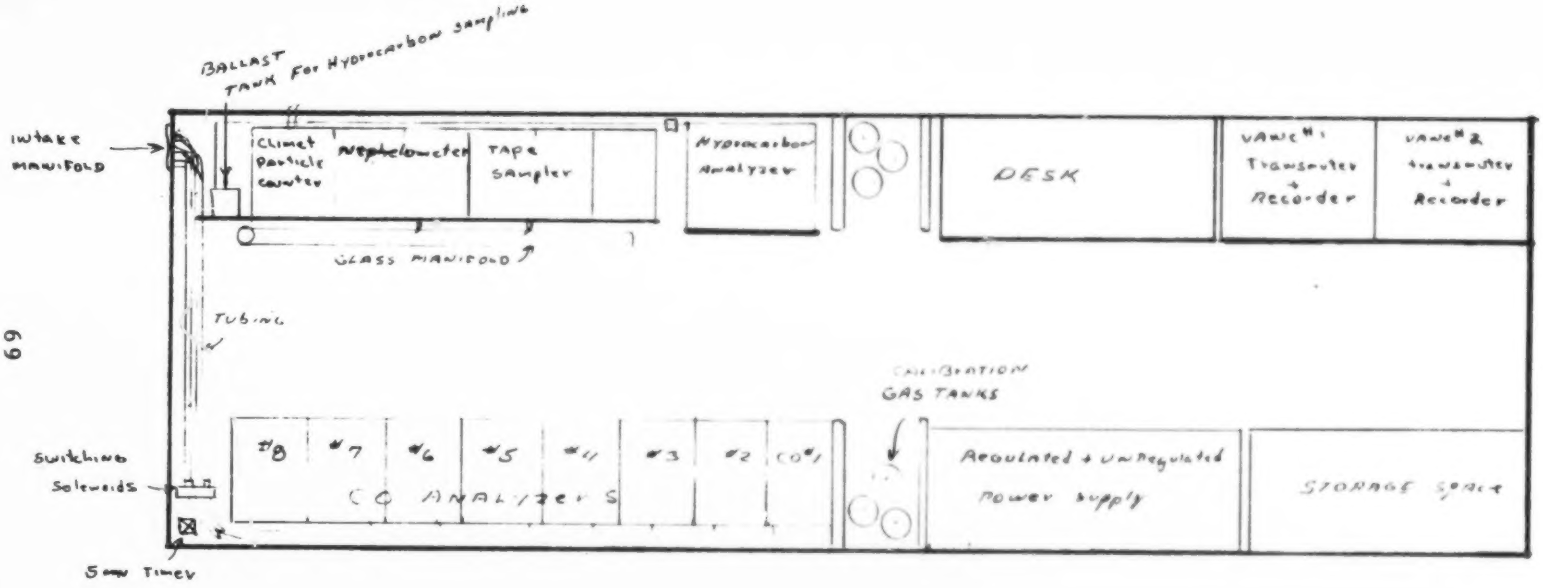

BALLAST TANK For Hydrocarbon sampling
INTAKE MANIFOLD
Climet Particle Counter
Nephelometer
Tape Sampler
Hydrocarbon Analyzer
GLASS MANIFOLD
DESK
VANE #1 Transmitter + Recorder
VANE #2 transmitter + Recorder
TUBING
CALIBRATION GAS TANKS
#8
#7
#6
#5
#4
#3
#2
CO #1
CO ANALYZERS
Regulated + unregulated power supply
STORAGE SPACE
Switching Solenoids
5 min Timer

Figure 3.1-1 General Air Pollution Trailer Layout

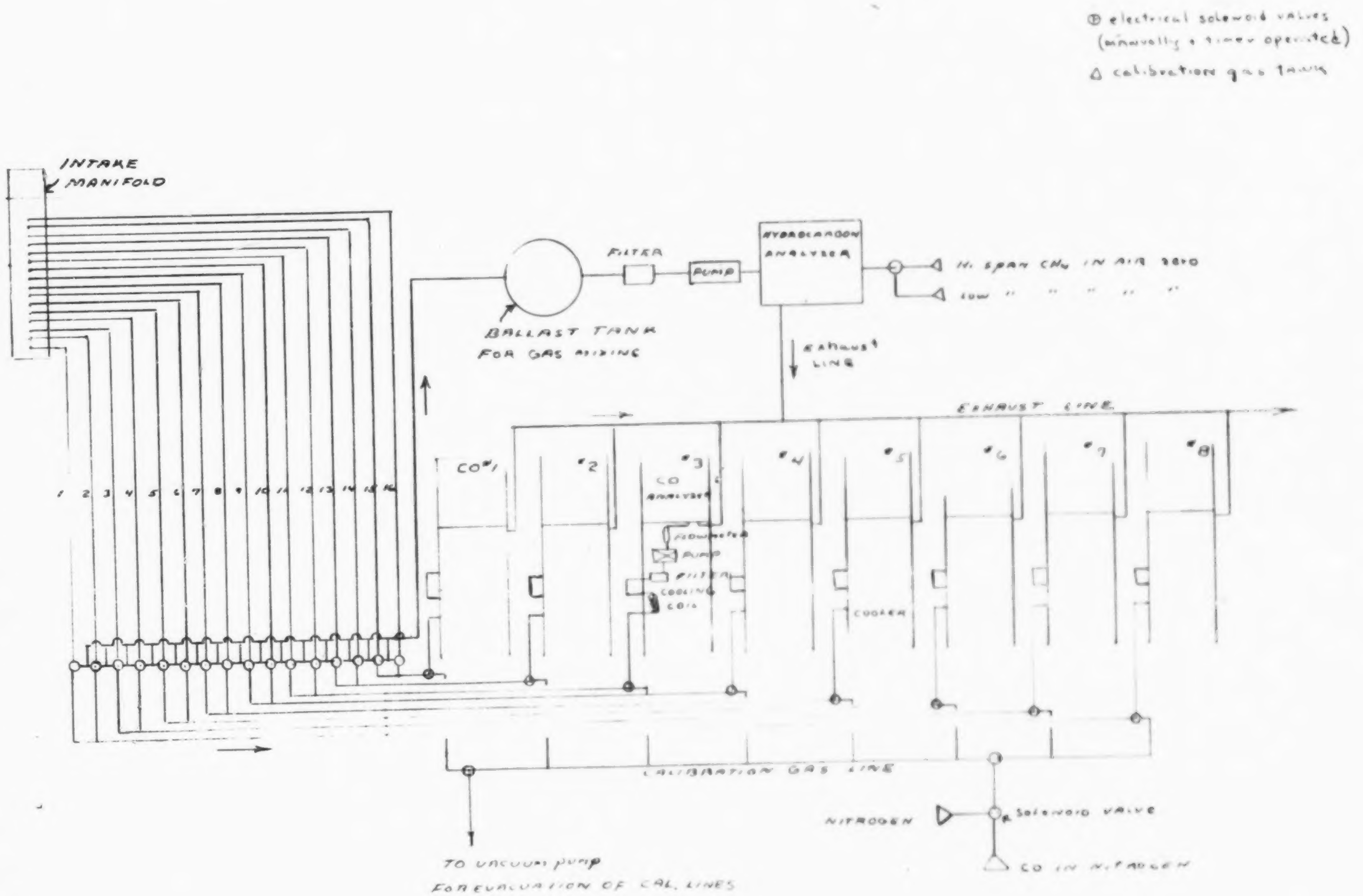

electrical solenoid valves
(manually & timer operated)
calibration gas tank
INTAKE MANIFOLD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
BALLAST TANK FOR GAS MIXING
FILTER
PUMP
HYDROCARBON ANALYSER
Hi span CH4 in AIR 2810
low " " " " "
exhaust LINE
EXHAUST LINE
CO #1
#2
#3
CO ANALYSER
FLOWMETER
PUMP
FILTER
COOLING COIL
#4
#5
COOLER
#6
#7
#8
CALIBRATION GAS LINE
TO VACUUM PUMP FOR EVACUATION OF CAL. LINES
NITROGEN
Solenoid valve
CO in NITROGEN

Figure 3.1-2 Flow Diagram for CO & Hydrocarbon System

One important study objective was to determine the pollution levels to which local community residents were subjected as a result of automobile emissions generated on the roadway. For this study, probes were placed inside and outside nearby buildings in order to define the Indoor-Outdoor CO concentration relationships at various distances from the roadway.

Inside the GE van, instruments continuously measured all important wind parameters. The sensing units were vector vanes capable of measuring wind speed, azimuth direction, and elevation. These vanes were strategically positioned at various site positions in order to define the local wind characteristics. Usually one vane was placed on the medial strip between the traffic lanes in order to sense traffic-generated turbulence and other wind data at the roadway. Another vane was placed away from the roadway in order to get overall wind information at the particular site. The number of vanes used and the locations selected, depended on site configuration and operator accessibility to vane for general maintenance and repair. In addition high volume air and tape samplers were positioned at the site to measure suspended particulates and trace metals (especially lead).

3.1.2 Air Quality Measurements

3.1.2.1 Carbon Monoxide

Carbon monoxide was measured using an infrared analysis technique. The measuring principle of the CO analyzer makes use of the specific radiation absorption band of carbon monoxide in the infrared range. A total of eight analyzers (Intertech Corp. Princeton, N.J.) were used in this study. The instrument was usually operated on the 0 to 100 ppm CO range and had the capability of measuring concentrations of less than one ppm CO in the sampled gas. The inherent zero and span drift for the instrument was $\leq 2\%$ of full scale per week. The analyzers were calibrated daily (except weekends) to ensure maximum accuracy. Nitrogen gas (zero grade) and a standard carbon monoxide (80 → 90 ppm) in N_2 mixture were used for calibration. Each analyzer sampled two probe locations for five minute intervals. Each CO analyzer was equipped with a pump which pulled air from one of two probe locations, through the polyethylene tubing, to the intake manifold of the air pollution van. From the manifold, the sampled gas from each location passed through a solenoid valve that was electrically controlled by a relay connected to a five minute timer. From this point, the gas flowed either to a CO analyzer or was by-passed to a ballast tank for mixing depending on whether the solenoid was or was not actuated. The timer controlled a total of 16 solenoid valves which in turn controlled the direction of the individual gas flows. During one five minute timer interval, eight probe locations were analyzed for carbon monoxide while the other eight were fed into a ballast tank where they were mixed and analyzed for total hydrocarbons.

A Hi Capacity pump was connected to the ballast tank to ensure that delay time due to solenoid switching was kept to a minimum.

Before going to the CO analyzer, the sample gas was passed through a porous filter in order to remove all particulate matter. Next, the gas was passed through a refrigerator containing a condensing coil which kept the amount of water vapor in the sample stream at a constant level. Interferences from water bands were thus eliminated since the amount of water was the same in both sample and calibration gases. Finally the gas passed through a flow regulator and into the CO analyzer for analysis. All exhaust gas is vented to the outside of the trailer.

Principal source errors in CO system were as follows:

1. Errors due to inaccurate instrument calibration
2. Inherent span and zero drifts in the instrument
3. Large humidity changes causing water vapor to interfere with CO absorption bands
4. The difficulty in reading hourly CO averages from the recording charts
5. Inability to differentiate between CO levels of two sampled locations due to small concentration differences
6. At any particular time, eight probe concentrations are not being sampled due to 5 minute cycling procedure

3.1.2.2 Hydrocarbons

Hydrocarbon concentrations were measured by a flame ionization method of detection. The sensor is a burner where a regulated flow of sample gas passes through a flame sustained by regulated flows of hydrogen and air zero. Hydrocarbon components in the sample stream undergo a complex ionization that produces electrons and positive ions. The ions produce an ionization current proportioned to the rate which carbon atoms enter the burner. Thus hydrocarbon concentrations are proportional to this ionization current. The hydrocarbon analyzer (Beckman Instruments, Fullerton, Calif.) that was used in this study, had a full scale sensitivity of 1 ppm CH_4 to 2% CH_4. The electronic stability at maximum sensitivity was ± 1% Full Scale. Reproducibility was 1% of full scale, for successive identical samples. All readout concentrations are expressed as ppm of CH_4, since CH_4 was the particular hydrocarbon present in the span gas.

Since only one hydrocarbon analyzer was available, a sampling scheme was used to obtain an average value for all probes sampled during each five minute cycling interval. The eight gases from probes not being analyzed for CO were mixed in the ballast tank from which an average hydrocarbon concentration was obtained.

3.1.2.3 Particulates and Trace Metals

In order to determine the amounts of particulates and trace metals in the air at each site, a 24 hour air sample was passed through a weighed porous filter. At the end of the sampling period, the filter was weighed again and the total weight of particulates deposited was calculated by subtracting the total weight from the initial filter weight. A High Volume air sampler was utilized for this portion of the study. Each sampler had its own calibrated flowmeter which indicated air flow rate through the porous filter. By taking a flowmeter reading before and after the test, an average flow rate was estimated. The total weight of particulate matter obtained divided by the volume of air sampled, gave a weight per cubic meter of particulate matter in the sampled air. The filter with the deposit was analyzed for lead and other trace metals by using an atomic absorption technique.

3.1.2.4 Tape Sampler

A tape sampler was also utilized to indicate the amount of particulates in the air at each site. A two hour air sample was pulled through a portion of tape by a pump. After the 2 hour sampling, the tape was automatically fed to a new unexposed portion of tape. A darkened circular spot was obtained whose darkened appearance is proportional to the amount of particulates in the air.

3.1.3 Traffic Measurements

Traffic measurements and pollutant concentrations are mutually interdependant. To secure the traffic parameters associated with vehicle emissions being recorded, data for volume, classification and speed were recorded at the location of each pollution monitoring site.

Traffic volumes were obtained by means of a Fischer Porter Punched Tape Recorder utilizing pneumatic road tubes for detection of vehicles. These vehicle impulses were stored on a memory code dish and digitally punched on a tape at 15 minute intervals. The punched tape was then run through a translator, the output of which was used to prepare the hourly traffic summary sheets.

Traffic volume counts are a product of axle impulses. The Fischer Porter counter automatically records one vehicle count for each two impulses received. On the F.D.R. Drive and the Grand Central Parkway, where commerical traffic is prohibited, no adjustment for multi-axle vehicles was necessary.

At the eight remaining sites, vehicle counts were recorded in duplicate; the punched tapes were compared for correlation; the resulting hourly readings edited to eliminate extraneous values and hourly values selected which conform to the established prevailing traffic pattern for each site. Classification counts of multi-axle vehicles were obtained manually and the machine counts were adjusted to reflect the reduction in transit of vehicles occasioned by the passage of multi-axle trucks over the detectors.

At site 3, the Brooklyn Queens Expressway at Hicks Street, classification counts were obtained only between the hours of 8:00 a.m. and 4:00 p.m. and at site 8, the Brooklyn Queens Expressway at Park and Navy Streets, classification counts were obtained between the hours of 7:00 a.m. and 6:00 p.m. The corresponding hourly traffic volumes were adjusted to reflect the affect of the multi-axle vehicles. The uncorrected 24 hour traffic summaries are available for comparison.

For the purpose of classification, those vehicles having three or more axles or two axle vehicles having a capacity of two tons or more, were considered in the category of trucks. All light trucks, pick ups, small vans and delivery wagons were included in the count by passenger cars. The multi-axle vehicles were identified as gas or diesel powered.

Under normal operating conditions, vehicular speeds approximated the posted speed limits. During periods of congestion, speeds dropped to minimum values. To measure these conditions, directional speeds were recorded at 15 minute intervals by observation and stop watch check. The beginning and ending times of traffic tieups were recorded. Radar speed recorders were also used to monitor speed. At Site 10, speed was also measured by recording the length of time required for passage of a vehicle through a 10 foot trap. The trap consisted of two pneumatic tubes spaced 10 feet apart which started and stopped 1 K Hertz signal which was recorded on magnetic tape. Speed readings were sampled at 5 minute intervals. The magnetic tape was then run through a Beckman Highspeed Digital Analyzer from which vehicle speeds were tabulated.

3.1.4 Meteorological Measurements

Meteorological sensors were incorporated into the monitoring scheme in recognition of the important effect of weather on the distribution and dispersion of pollutants. Vector Vane equipment, manufactured by Meteorology Research, Inc. of Altadena, Calif. was used to monitor wind conditions. The Vector Vane is a lightweight, quick response, low threshold instrument which, with its associated electronic package, measures wind azimuth (0° - 540°), wind elevation angle ($+60^\circ$ to -60°), and wind speed (0-80 mph). The response characteristics of the Vector Vane sensor are as follows:

Starting Threshold	Speed	1.0 mph
	Direction	1.0 mph
Response Distance	Speed	2-3 feet
Delay Distance	Direction	2-3 feet
Damping Ratio	Direction	0.4 - 0.7
Overshoot	Direction	less than 10%
Linearity	Speed	± 1% of pitch
	Direction	± 1%

The Sigma Meter portion of the Vector Vane system continuously calculated the standard deviation (sigma) of the fluctuations of the azimuth and elevation angles. A five-second sampling time for the sigma computations was used almost exclusively since the main interest lies in the higher frequency components of turbulence. The Vector Vane Sigma Meter/Transmuter provided analog outputs for each of the above wind functions in the form of a 0-5 VDC signal.

Two complete Vector Vane systems were used during the course of this study. One sensor was usually located near the probe plane and on the median of the road being studied. It was expected that this vane, being as close to the traffic as possible without being in danger of damage, would record any turbulence generated by the motion of the vehicles themselves as well as natural turbulence. Turbulent atmosphere motions generated by passing traffic were expected to be of very limited scale in both time and space. It is for this reason that a sampling time constant of 5 seconds was chosen for the sigma computations for this vane. The remaining system was installed, whenever practical, at a higher elevation and away from nearby obstructions, to obtain a record of the more general wind conditions in the area. A five second constant was also used for this system to permit comparison with the road wind system.

The azimuth, sigma azimuth, elevation, and sigma elevation channels from each system were recorded on four channel Esterline Angus strip chart recorders. The wind speed channel from each system was recorded on one channel of a shared two channel Esterline Angus panelgraph recorder. The wind systems were operated twenty-four hours per day at each site except for shutdowns due to damaged or malfunctioning equipment. The strip chart recorders were operated at a speed of three inches per hour.

Strip chart traces were manually digitized with data averaged and recorded at one hour intervals. The calculation of the sigma azimuth function from the strip chart trace was somewhat impaired by the electrical "crossover" experienced in the azimuth channel. Although the 540 azimuth format and a special switching system reduced these crossovers to a minimum, their effect on sigma azimuth was significant, especially during turbulent weather. The contributions of this crossover to the sigma azimuth value were subjectively removed, whenever possible, during digitization of the chart record. After digitization, the data was keypunched and processed on the GE-635 computer with specially developed software. The program translated the voltages read from the strip charts to angles and velocities as well as performing a statistical analysis on the data. The azimuth angle was translated according to the following relation:

Azimuth Angle = $(X - C)\ .540^\circ$ for upright sensor
= $[1 - X-C)]\ .540^\circ$ for inverted sensor

where: X is the number read from the strip chart
C is an orientation factor used to translate the axes so that 0° is parallel to the road.

A value equal to 360° was added or subtracted from the answer as needed to keep the angles in the 0° to 360° range. The sigma azimuth and sigma elevation values were determined by simply multiplying the strip chart readings by 45° and 15° respectively, the full scale values of the functions. Elevation angles were determined by the following formula:

Elevation Angle = $(X - 120^\circ) - 60^\circ$

where: X is again the number read from the strip chart (range 0 to 1.0)

Wind speed values were read directly from the charts and required no translation. All missing data was designated by -1. or (-99. where positive and negative values inherent in the data would make -1. ambiguous).

A statistical analysis of each wind function was performed and means, medians, and standard deviations were printed. In the case of sigma azimuth, sigma elevation, and wind speed, the means and standard deviations were plotted vs time of day. However, azimuth and elevation angle data did not easily lend itself to this type of analysis so a table of frequency of occurrence and an associated histogram were printed instead.

Finally, the wind vector was resolved into components and the statistical analysis was again performed. The hourly means and standard deviations of each of the three components was plotted. On the print-outs, the vertical velocity is identified as W (+ up, - down), the component parallel to the road is identified as U (+ when blowing from direction of 0° azimuth), and the component perpendicular to the road is V (+ when azimuth angle is in the range of 0° to 180°). The sign conventions used are portrayed in figure 3.1-3. The data reduced and processed in this manner was used in the regression and correlation analysis discussed in section 3.3.2. The complete set of wind observations and the analysis can be found in Appendix C.

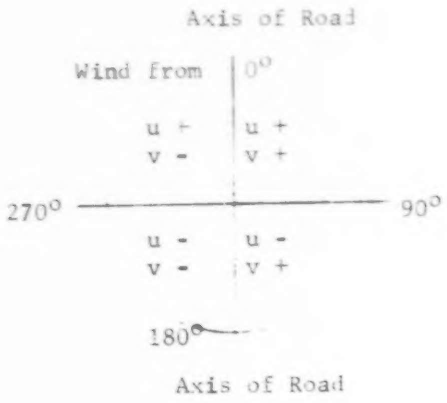


Figure 3.1-3 Sign Conventions for Horizontal Wind Components

3.2 Regression and Correlation Analyses

Regression and correlation analyses were performed to determine whether the relationship between environmental variables and carbon monoxide and hydrocarbon concentrations could be predicted mathematically.

3.2.1 Carbon Monoxide

The CO study was aimed at determining the effects of the various wind parameters on the CO concentrations using linear regression.

3.2.1.1 Regression Equation

The relationship between the wind parameters; i.e., sigma azimuth, sigma elevation, and wind speed, and the CO concentration was assumed to be of the form

$$C = K_o \ \sigma_{AZ}^{K_1} \ \sigma_{EL}^{K_2} \ V^{K_3} \qquad 3.2\text{-}1$$

Where

C = average hourly carbon monoxide concentration

σ_{AZ} = average hourly standard deviation of the wind azimuth angle

σ_{EL} = average hourly standard deviation of the wind elevation angle

V = average hourly wind speed

K_o, K_1, K_2, K_3 = unknown constants to be estimated

To use this equation in linear regression analysis, it is necessary to take the natural logarithm of both sides of the equation. Thus

$$\ln C = \ln K_o \ \sigma_{AZ}^{K_1} \ \sigma_{EL}^{K_2} \ V^{K_3} \qquad 3.2\text{-}2$$

and by using the properties of the natural logarithm we obtain

$$\ln C = \ln K_o + K_1 \ln \sigma_{AZ} + K_2 \ln \sigma_{EL} + K_3 \ln V \qquad 3.2\text{-}3$$

If we now let

$Y = \ln C$

$X_1 = \ln \sigma_{AZ}$

$X_2 = \ln \sigma_{EL}$

$X3 = \ln V$

$B_o = \ln K_o$

$B_1 = K_1$

$B_2 = K_2$

$B3 = K3$

then the above equation becomes

$$Y = B_o + B_1 X_1 + B_2 X_2 + B_3 X_3 \qquad 3.2\text{-}4$$

which is the form used in the regression analysis.

A computer program was developed to do the numerical computation in the regression analysis on the G.E. 635 computer system. The program accepted as input a set of N observations for p + 1 variables of the form

$$\begin{bmatrix} Y_1 & X_{11} & X_{12} & \cdots\cdots\cdots & X_{1p} \\ Y_2 & X_{21} & X_{22} & \cdots\cdots\cdots & X_{2p} \\ \vdots & & & & \\ Y_n & X_{n1} & X_{n2} & \cdots\cdots\cdots & X_{np} \end{bmatrix}$$

where the row ($Y_1 \; X_{11} \; X_{12} \; \ldots\ldots\ldots X_{1p}$) represents one particular observation of the p + 1 variables.

For a particular run, one of the columns is selected as a dependent variable (Column one in the above matrix is chosen for convenience) and the remaining columns as the independent variables. Then using the linear model

$$Y = B\,X$$

Where

$$Y = \left\{ \begin{matrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{matrix} \right\}, \quad B = \left\{ \begin{matrix} B_o \\ B_1 \\ \vdots \\ B_P \end{matrix} \right\}, \quad X = \left\{ \begin{matrix} 1 & X_{11} & X_{12} & \cdots & X_{1P} \\ 1 & X_{21} & X_{22} & \cdots & X_{2P} \\ & & & & \\ 1 & X_{N1} & X_{N2} & \cdots & X_{NP} \end{matrix} \right\} \qquad 3.2\text{-}5$$

the least squares estimates of

$B^T = \left[B_o, B_1, \ldots, B_P \right]$ ("T" means transpose),

namely $b^T = \left[b_o, b_1 \ldots, b_p \right]$ are computed

using the equation

$$b = \left[X^T X \right]^{-1} X^T Y \qquad (\text{"-1" means inverse}) \qquad 3.2\text{-}6$$

and the predicted values of Y, namely, $\acute{Y}$ are computed using the relation

$$\acute{Y} = Xb \qquad 3.2\text{-}7$$

A measure of the success of the regression equation in explaining the variation in the data is given by the multiple correlation coefficient, R, and is computed using the equation

$$R = \sqrt{\frac{b^T \; X^T \; Y \; - \; N \; \overline{Y}^2}{Y^T \; Y \; - \; N \; \overline{Y}^2}} \qquad 3.2\text{-}8$$

where $\overline{Y} = \frac{1}{N} \sum_{i=1}^{N} Y$ is the mean value of the N dependent variable observations. The values of R lie between zero and one. The closer to unity R is the more successful the regression equation explains the data variation.

A measure of the linear relationship between the dependent variable Y and any independent variable X_j is given by the simple correlation coefficient, r_{1j} and is computed from the equation

$$r_{1j} = \frac{\sum_{i=1}^{N} (Y_i - \overline{Y})(X_{ij} - \overline{X}_j)}{\left[\sum_{i=1}^{N} (X_{ij} - \overline{X}_j)^2\right]^{1/2} \left[\sum_{i=1}^{N} (Y_i - \overline{Y})^2\right]^{1/2}} \qquad 3.2\text{-}9$$

where $\overline{X}_j$ is the mean value of the N observations of the j^{th} independent variable

The values of r_{1j} lie between -1 and 1. The magnitude of r_{1j} determines the strength of the linear relationship between the variable, whereas the sign of r_{1j} tells whether Y tends to increase, or decrease, with increasing X_j. The value of r_{1j} will be equal to ± 1 if, and only if, the points (X_{ij}, Y_i) lie on some straight line.

Since Y represents the natural logarithm of the CO concentration and X_1, X_2, and X_3 represent the logarithms of the sigma azimuth angle, sigma elevation angle, and wind speed respectively, r_{11} , r_{12} , and r_{13} represent the simple correlation coefficients between the logarithms of the CO concentrations and the wind speeds respectively. The correlation coefficient, as stated previously, is a measure of the linear relationship between two variables. However, it is also a measure of how well an equation of the form

$$C = AZ^M$$

describes the relationship between the variables, C and Z where Z is either σ_{az} (sigma azimuth angle), $_{el}$ (sigma elevation angle), or V (wind speed).

3.2.1.2 CO Regression & Correlation Analyses

Correlation analyses were performed, using the CO and meteorological data gathered at each site, to evaluate the effectiveness of the postulated regression equation. The numerical results of these analyses and the location of the data sensors, are shown in Tables 3.2-1 to 3.2-12. The traffic flow rate data provided by the New York State Transportation Administration on April 13, 1971 was used.

NUMERICAL RESULTS OF 54th AND SUTTON PLACE CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
4130-4570	4	Too few sample points							
4420-4880	10	9.55	-3.48	.98	-.85	-.76	-.07	.38	.88
4700-5200	10	5.85	-1.60	1.45	-1.08	.04	.22	-.37	.62
4990-5510	7	-.28	-.75	3.12	-.10	-.10	.35	-.23	.53
5270-5830	6	.84	-.59	2.03	.01	.31	.81	-.37	.86
5560-6140	4	Too few sample points							
5840-6460	5	2.01	1.06	-1.37	.45	.65	.53	-.36	.74
6130-6770	7	-.38	-.38	1.33	.97	.63	.73	.59	.78
6410-7090	6	2.19	1.83	-.57	-.93	.94	.89	.59	.95
6700-7400	4	Too few sample points							

CO data obtained 12' above the sidewalk alongside the instrumentation ran it the southwest corner of the tunnel

Meteorlogical data obtained from Vane 1

Traffic flow rate intervals selected from total traffic flow rate data.

Table 3.2-1

NUMERICAL RESULTS OF BROOKLYN QUEENS EXPRESSWAY AT HICKS STREET CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr.)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
2840-3140	3		Too few sample points						
3410-3770	5	-8.24	.24	2.32	3.04	.61	.66	.34	.99
3700-4080	5	-24.8	-3.91	13.9	2.15	-.02	.02	.47	.85
3980-4400	5	6.44	-.86	.31	-.98	-.37	-.55	-.27	.57
4270-4710	10	4.51	1.42	-2.63	.70	.09	-.23	-.09	.55
4550-5030	10	3.24	.52	-.55	-.18	.22	.09	-.27	.35
4840-5340	12	1.34	-.05	.94	-.38	.31	.29	-.46	.50
5120-5660	15	5.35	-.87	.42	-.49	-.11	.04	-.29	.47
5410-5970	15	1.66	-1.96	2.96	-.41	-.31	-.14	-.15	.65
5690-6290	8	1.48	.63	-4.52	-.91	-.36	-.48	-.13	.65
5980-6600	5	-3.05	-.52	2.93	-.19	-.19	.45	-.36	.68
6260-6920	6	3.67	-.15	.08	-.28	-.37	-.30	-.44	.50

CO data obtained 14' above the medial strip

Meteorological data obtained fron Vane 2

Traffic flow rate intervals selected from total traffic flow rate data

Table 3.2-2

NUMERICAL RESULTS OF HUGH J. GRANT CIRCLE CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_0	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
1580-1740	2	Too few sample points							
1770-1950	7	.21	-5.28	-1.40	3.01	-.60	-.68	.50	.88
1960-2160	8	11.00	-.44	-1.93	-.27	-.16	-.43	-.14	.49
2150-2370	14	7.88	-.39	-1.32	.32	-.44	-.32	.44	.56
2340-2580	14	7.54	1.64	-3.62	.33	.48	-.45	.29	.78
2530-2790	8	10.30	-1.26	-.93	-.01	-.72	-.43	.69	.74
2720-3000	14	8.02	.30	-2.29	.41	-.36	-.57	.32	.64
2910-3210	11	4.87	.35	-1.27	.32	-.14	-.40	.46	.63
3100-3420	4	Too few sample points							

CO data obtained 16' above the westbound lanes near the outer wall at the mouth of the tunnel

Meteorological data obtained from Vane 1

Traffic flow rate intervals selected from westbound traffic flow rate data

Table 3.2-3

NUMERICAL RESULTS OF NELSON AND JESSUP AVES CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
4550-5030	7	13.20	-1.22	-1.26	-2.15	.22	.06	-.88	.96
4930-5450	14	1.50	-.36	1.08	-.71	.12	.51	-.54	.68
5310-5870	15	1.89	-.94	1.18	-.01	-.47	.001	.12	.65
5690-6290	25	3.98	-.64	.42	-.57	-.05	.05	-.32	.49
6070-6710	16	5.70	-.73	.25	-1.06	.06	.17	-.50	.69
6450-7130	2828	5.37	-1.11	1.33	-.77	.29	.42	-.46	.63
6830-7550	22	2.51	-.42	.66	-.49	.45	.54	-.58	.63
7210-7970	22	-5.15	-.57	-2.84	.78	.25	.56	-.38	.73
7590-8390	14	-2.35	-.66	2.16	.38	.13	.44	-.22	.65
7970-8810	5	2.36	-.46	.59	-.19	.52	.64	-.69	.89

CO data obtained 26' above the medial strip

Meteorological data obtained from Vane 1.

Traffic flow rate intervals selected from total traffic flow rate data

Table 3.2-4

NUMERICAL RESULTS OF BRUCKNER EXPRESSWAY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
1880-2080	3	Too few sample points							
2170-2390	12	1.26	-1.11	1.82	-.50	-.07	.21	-.75	.86
2450-2710	22	3.01	.69	-1.00	-.67	.23	.31	-.62	.65
2740-3020	15	1.08	-.16	-.59	-.20	.41	.48	-.34	.65
3020-3340	10	3.29	.69	-1.32	-.23	-.05	-.35	.36	.51
3310-3650	16	2.76	.14	-.37	-.32	-.03	-.08	-.57	.59
3590-3970	21	1.97	-.21	.43	-.33	.16	.29	-.56	.57
3880-4280	12	3.94	.20	-.67	-.67	.01	.01	-.64	.73

CO data obtained 14' above the medial strip

Meteorological data obtained from Vane 2

Traffic flow rate intervals selected from total traffic flow rate data

Table 3.2-5

NUMERICAL RESULTS OF BRUCKNER EXPRESSWAY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
1880-2080	6	.004	-1.81	2.36	.36	-.07	.18	.26	.83
2170-2390	14	2.58	-.26	.05	-.26	-.28	-.25	-.26	.40
2450-2710	24	3.31	-.58	.31	-.41	-.13	-.11	-.34	.52
2740-3020	21	4.18	-1.99	1.13	-.25	-.62	-.46	.10	.70
3020-3340	19	33.65	-1.67	1.63	-.82	-.09	.03	-.41	.64
3310-3650	19	3.42	-.50	.12	-.38	-.26	-.28	-.34	.57
3590-3970	21	2.73	-.67	.60	-.23	.02	.08	-.27	.41
3880-4280	12	4.40	-2.07	1.71	-.43	-.32	-.30	-.08	.57

CO data obtained 25' above the ground at the south side of the road

Meteorological data obtained from Vane 1

Traffic flow rate intervals selected from total traffic flow rate data

Table 3.2-6

NUMERICAL RESULTS OF GRAND CENTRAL PARKWAY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
3190-3530	9	2.78	.03	-.09	-.90	-.02	.43	-.84	.84
3950-4370	8	-6.56	.78	3.04	-.30	.88	.88	-.84	.93
4710-5210	8	2.87	2.40	-2.98	-.44	.74	.47	-.73	.84
5470-6050	12	1.93	1.18	-.89	-.56	.61	.47	-.39	.69
6230-6890	10	9.90	.27	-3.32	-.04	.01	-.71	.05	.72
6990-7730	11	-1.60	.73	.51	.71	.32	.23	.57	.65
7750-8570	17	5.20	-.08	-.55	-.96	.62	.31	-.78	.79
8510-9410	11	6.23	.71	-2.11	-.63	.24	-.13	-.49	.80
9270-10,250	7	4.92	-.60	.02	-.67	.29	.03	-.82	.91

CO data obtained 10'above the medial strip

Meteorological data obtained from Vane 2

Traffic flow rate interval selected from total traffic flow rate data

Table 3.2-7

NUMERICAL RESULTS OF GRAND CENTRAL PARKWAY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (VEH/HR.)	NO. OF SAMPLE POINTS	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
3190-3530	9	.27	-1.55	3.40	-2.32	-.24	.09	-.35	.68
3950-4370	7	4.68	-4.70	4.08	- .42	-.94	-.82	-.40	.97
4710-5210	8	1.23	-4.46	5.61	- .45	-.74	-.53	-.35	.94
5470-6050	12	6.15	.89	-2.99	.25	-.43	-.51	-.36	.55
6230-6890	10	13.21	-1.33	-2.70	- .67	-.81	-.68	-.34	.84
6990-7730	14	1.91	- .21	- .04	.46	-.10	-.08	-.46	.50
7750-8570	16	.70	-2.83	-3.68	.07	-.36	-.03	-.02	.78
8510-9410	11	4.09	-1.99	1.27	.31	-.64	-.32	-.13	.83
9270-10,250	6	5.65	-1.70	.09	.55	-.56	-.17	.26	.90

CO data obtained 20' above the center of the northbound service road
Meteorological data obtained from Vane I
Traffic flow rate intervals selected from total traffic flow rate data

TABLE 3.2.8

NUMERICAL RESULTS OF BROOKLYN QUEENS EXPRESSWAY AT PARK & NAVY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (VEH/HR)	NO. OF SAMPLE POINTS	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
3040-3360	5	-3.56	1.86	-1.87	2.64	.84	.34	.01	.94
3800-4200	3	Too few sample points							
4180-4620	15	3.59	.10	- .01	-1.12	.28	.34	-.56	.56
4560-5040	21	-1.92	- .08	1.97	- .36	.46	.49	-.33	.52
4940-5460	17	-1.35	1.91	- .95	- .20	.64	.52	-.30	.66
5320-5880	22	-1.39	1.03	.28	- .31	.48	.33	-.34	.51
5700-6300	17	1.72	.09	.36	- .43	.22	.18	-.26	.29
6080-6720	10	- .71	-2.25	4.72	- .92	.50	.68	-.84	.96
6460-7140	7	4.21	.31	- .42	-1.27	.47	.60	-.89	.90
6840-7560	3	Too few sample points							

CO data obtained 10' above the center of the road
Meteorological data obtained from Vane 2
Traffic flow rate intervals selected from total traffic flow rate data

TABLE 3.2.9

NUMERICAL RESULTS OF BROOKLYN QUEENS EXPRESSWAY AT PARK AND NAVY CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (Veh/Hr)	# of Sample Points	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
3040-3360	0	Too few sample points							
3800-4200	2	Too few sample points							
4180-4620	14	.96	-.05	.74	-.33	.83	.79	-.71	.88
4560-5040	27	-1.26	.73	.93	-.39	.73	.72	-.26	.81
4940-5460	21	.33	1.33	-.57	-.27	.68	.55	-.17	.76
5320-5880	21	1.45	.01	.54	-.48	.54	.46	-.73	.77
5700-6300	15	.12	-.54	1.72	-.32	.67	.70	-.60	.79
6080-6720	9	1.39	1.33	-1.34	.002	.46	.06	-.71	.81
6460-7140	6	3.31	-.60	.45	-.58	.07	-.23	-.84	.87
6840-7560	2	Too few sample points							

CO data obtained 20' above the west side of the road

Meteorological data obtained from Vane 1

Traffic flow rate intervals selected from total traffic flow rate data

Table 3.2-10

NUMERICAL RESULTS OF CANAL STREET CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (VEH/HR)	NO. OF SAMPLE POINTS	b_o	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
890-990	5	.42	.05	1.22	-.32	.11	.53	.21	.59
990-1090	5	-.94	-.42	2.16	.19	.05	.83	.73	.92
1080-1200	9	2.47	-.11	-.46	.78	.04	-.13	.46	.53
1180-1300	20	2.02	.09	-.10	.33	.19	-.27	.32	.39
1270-1410	16	1.15	.86	-.16	-.30	.36	-.24	.11	.50
1370-1510	10	-1.74	.99	1.16	-.75	.85	.58	.72	.92
1460-1620	3	Too few sample points							
1560-1720	3	Too few sample points							
1650-1830	0	Too few sample points							

CO data obtained 20' above the westbound lanes

Meteorological data obtained from Vane 2

Traffic flow rate intervals selected from total traffic flow rate data.

TABLE 3.2-11

NUMERICAL RESULTS OF CANAL STREET CO REGRESSION ANALYSIS

TRAFIC FLOW RATE INTERVAL (VEH/HR)	NO. OF SAMPLE POINTS	b_0	b_1	b_2	b_3	r_{11}	r_{12}	r_{13}	R
890-990	6	4.98	-1.00	.18	- .53	-.79	-.57	-.43	.97
990-1090	7	1.88	2.97	-4.28	1.65	.59	.43	.19	.69
1080-1200	18	1.07	- .14	.85	- .42	.12	.10	-.09	.28
1180-1300	28	3.50	.58	-1.61	.25	-.04	-.08	-.01	.15
1270-1410	29	1.71	.83	-1.13	.26	.16	.07	.07	.23
1370-1510	22	1.81	- .03	- .18	.26	-.03	-.005	.10	.15
1460-1620	15	1.45	- .06	.29	- .43	-.02	-.09	-.23	.24
1560-1720	8	-1.36	2.20	-.31	-1.11	.43	-.16	-.53	.65
1650-1830	5	3.05	1.35	-3.90	1.88	.18	.13	.27	.99

CO data obtained 50' above the ground, 16' morth of the road

Meteorological data obtained from Vane 1

Traffic Flow Rate intervals selected from total traffic flow rate data

TABLE 3.2-12

In order to determine the direct effects of the various wind parameters on the CO concentrations, the influence of the traffic flow rates on the concentrations had to be eliminated. This was effectively achieved by choosing a traffic flow rate interval "small" enough so that the values of the interval for our purpose could be considered constant and then using only those data points for the wind parameters and CO concentrations in the analysis that corresponded to the traffic flow rates in the chosen interval. Since, in general, the traffic flow rates for each site varied considerably, several traffic flow rate intervals were chosen and a separate regression and correlation analysis was performed on the data that corresponded to each interval.

The traffic flow rate intervals were selected for each site to provide approximately ten intervals spanning the range of total traffic. The analysis was performed by checking all the reliable traffic flow rate values to see if they fell in the traffic flow rate interval chosen for the particular run. Whenever a value was in the interval, the day and the hour of that value was noted. Then the mean CO concentration, the mean sigma azimuth angle, the mean sigma elevation angle, and the mean wind speed for that particular day and hour were checked to see if any of the values were missing. If one or more were missing, the computer would disregard all those values for the day and hour and check the values of the CO and meteorological data for the day and hour that corresponded to the next traffic flow rate that fell in the interval. If none of the values were missing, the logarithm of each value was computed and stored as the first observation in the regression array. This process was continued until the CO concentration and wind parameters for the day and hour that corresponded to the last traffic flow rate that fell into the interval were checked and either discarded or else the logarithm of each value was computed and the four values stored as the last observation in the regression array.

If the number of observations in a regression array was four or less, no regression or correlation analysis was performed since the results would provide little or no information regarding how well the proposed regression model describes the variation in the data. This is because the regression curve would pass through each data point and the multiple correlation coefficient would always be unity.

By examination of the data in Tables 3.2-1 to 3.2-12 it can be seen that the simple correlation coefficients, r_{11}, r_{12}, r_{13} and the multiple correlation coefficient, R, show large variations. It must be concluded, therefore, that the postulated regression equation does not adequately describe the effects of the wind parameters on the carbon monoxide concentrations.

Another regression model was formulated to see if a better fit of the data could be obtained. The new postulated model was

$$C = K_o (\sigma_{AZ} \sigma_{EL} V)^{K_1}$$

where C = mean hourly CO concentration

σ_{AZ} = mean hourly standard deviation of the wind azimuth angle

σ_{EL} = mean hourly standard deviation of the wind elevation angle

V = wind speed

K_o K_1 = constants to be estimated

The linearized form of the model is

$$\ln C = \ln K_o + K_1 \ln (\sigma_{AZ} \sigma_{EL} V)$$

where ln is the natural logarithm function

Letting $Y = \ln C$

$X_1 = \ln (\sigma_{AZ} \sigma_{EL} V)$

$B_o = \ln K_o$

$B_1 = K_1$

and substituting in the above equation yields

$$Y = B_o + B_1 X_1$$

which is the form used in the computer program

Table 3.2-13 shows the numerical results of the revised regression equation, using data gathered for the Brooklyn Queens Expressway at Hicks Street site. It can be seen that the correlation coefficient, r_{11} between the CO concentration and the product of the sigma azimuth, sigma elevation, and wind speed, varies between -.77 and .95. The multiple correlation coefficient, R, varies between .05 and .95. Thus the new postulated model does not explain the data variation as well as the original postulated model.

3.2.2 Hydrocarbon

The hydrocarbon study was aimed at determining the effect of the change in traffic flow rate on the hydrocarbon concentrations.

3.2.2.1 Regression Equation

The relationship between the hydrocarbon concentration and the traffic flow rate was assumed to be linear so that the relationship could be written in the form

$$H = B_o + B_1 \dot{N}$$

NUMERICAL RESULTS OF BROOKLYN QUEENS EXPRESSWAY AT HICKS STREET CO REGRESSION ANALYSIS

TRAFFIC FLOW RATE INTERVAL (VEH/HR)	NO. OF SAMPLE POINTS	b_o	b_1	r_{11}	R
2840-3140	3	.74	3.2×10^4	.95	.95
3410-3770	5	31.10	-8.27×10^2	-.77	.77
3700-4080	5	46.35	-1.80×10^4	-.46	.46
3980-4400	5	13.19	1.20×10^4	.68	.68
4270-4710	10	20.91	1.00×10^3	.05	.05
4550-5030	10	23.14	- .07	-.05	.05
4840-5340	12	23.30	2.10×10^3	.06	.06
5120-5660	15	13.60	1.32×10^4	.34	.34
5410-5970	15	7.18	1.97×10^4	.56	.56
5690-6290	8	11.53	1.84×10^4	.55	.55
5980-6600	5	23.60	-3.18×10^3	-.22	.22
6260-6920	6	19.59	1.41×10^3	.34	.34

CO data obtained 14' above the medial strip
Meteorological data obtained from Vane I
Traffic flow rate interval selected from total traffic flow rate data.

TABLE 3.2-13

where H = mean hourly hydrocarbon concentration

$\dot{N}$ = mean traffic flow rate

B_o, B_1 = unknown constants to be estimated

Since the equation is linear, it was used directly in the computer program for the analysis. Therefore, in the program, p, the number of independent variables, was equal to one and that variable was the traffic flow rate. The hydrocarbon concentration was designated as the dependent variable in this analysis. B_o and B_1 were the constants in the postulated regression model and their least squares estimates were designed b_o and b_1 respectively. The simple correlation coefficient, r, between the hydrocarbon concentrations and the traffic flow rates was, in itself, a measure of the linear relationship between the variables for each site.

3.2.2.2 Results of the Hydrocarbon Regression and Correlation Analysis

The hydrocarbon concentration and traffic flow rate data for all twenty-four hours of each day was used for seven of the nine sites analyzed. Since the only reliable traffic flow rate data at B.Q.E. at Hicks Street was for the hours of 0800 through 1500 and for the hours of 0700 through 1700 at B.Q.E. at Park and Navy Streets, the analysis for these sites was done using the hydrocarbon concentration and traffic flow rate data for those hours only.

As can be seen from Table 3.2-14 which summarizes the numerical results of the analysis, the magnitudes of the correlation coefficients between the hydrocarbon concentrations and the traffic flow rates for eight of the nine sites analyzed are very, very small. Since the magnitude of the correlation coefficient provides a measure of the usefulness in the regression model of the term containing B_1, it can be concluded that a model of the form

$$H = B_o$$

Where H = hydrocarbon concentration

B_o = constant

would describe the data variation for eight sites as well as the postulated model. In fact, the model

$$H = \overline{H} ,$$

where $\overline{H}$ is the mean value of the hydrocarbon measurements, seems to provide as good of fit of the data at B.Q.E. at Hicks Street as the regression model. Figure 3.2-1 illustrates this. It can also be seen from Figure 3.2-1 that the relationship does not appear to be linear. Hence the correlation coefficient is only .19.

The coorelation coefficient between the hydrocarbon concentrations and the traffic flow rates for the George Washington Bridge is .65.

NUMERICAL RESULTS OF HYDROCARBON REGRESSION ANALYSIS

SITE	# OF SAMPLE POINTS	b_o	b_1	r
1. 54th & Sutton Place	111	6.97	.00005	.05
2. Brooklyn Battery Tunnel		No Analysis Performed		
3. B.Q.E. at Hicks St.	50	3.05	.00040	.19
4. H.J. Grant Circle	192	5.68	.00026	.21
5. Nelson & Jessup Aves.	210	3.36	.00007	.23
6. Bruckner Expy.	226	3.30	-.00005	-.13
7. Grand Central Pky.	258	10.01	.00030	.30
8. B.Q.E. at Park & Navy	137	8.10	.00058	.29
9. Canal Street	160	8.51	.00284	.26
10. Geo. Washington Bridge	323	8.70	.00063	.65

Legend

b_o Least squares estimate of B_o in the regression model

b_1 Least squares estimate of B_1 in the regression model

r Correlation coefficient between hydrocarbon concentrations and traffic flow rates

TABLE 3.2-14

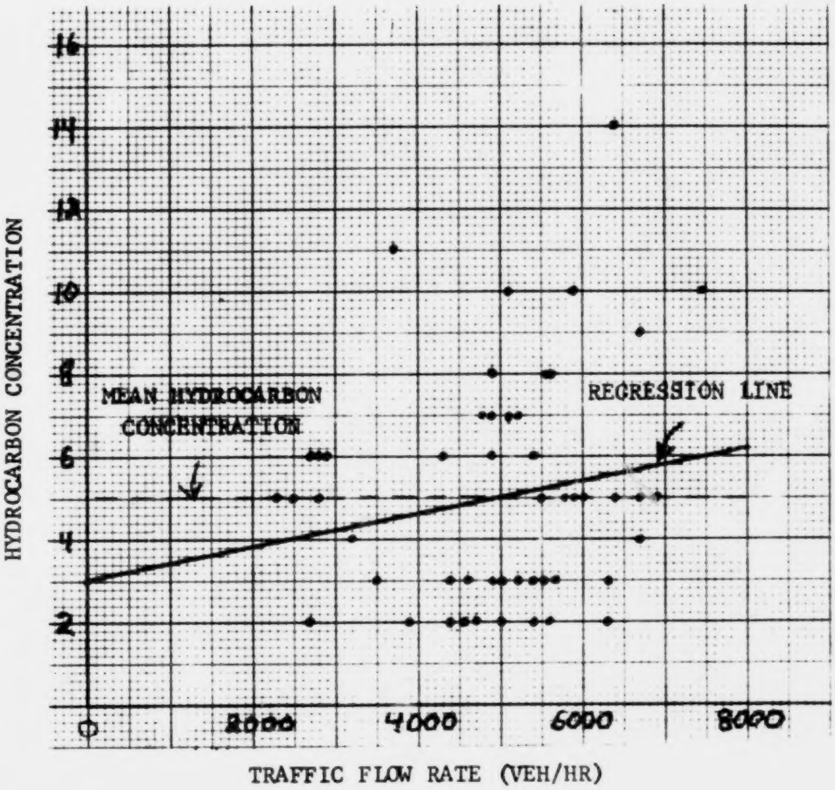


Figure 3.2-1 - Hydrocarbon Concentration vs. Traffic Flow Rate for Brooklyn Queens Expressway at Hicks Street

This value is also too small to conclude that there is a linear relationship exhibited between the variables. Hence, there does not appear to be a linear relationship between the hydrocarbon concentrations and the traffic flow rates for the nine sites analyzed and for this reason the postulated regression model does not adequately describe the data variation of the two variables for these sites.

3.3 Model Development

Exponential decay of carbon monoxide concentration with increasing height has been previously reported(1) and has been theoretically justified by Sontowski and Dworetzky(2). These workers have found that the following relation may be applied to define the concentrations as a function of vertical distance:

$$C = \frac{M\dot{N}}{aW\left(D + \frac{V}{a}\right)} e^{-az} \qquad 3.3\text{-}1$$

where:

$M = \frac{\text{Mass}}{\text{Vehicle mile}}$

$\dot{N}$ = Traffic flow rate (vehicles/hr.)

a = Constant found to be .015 - 025 ft.^{-1}

W = Width of cut

D = Eddy Diffusion Coefficient

V = Wind velocity

z = Height above vehicle exhaust plane

C = Concentration

The applicability of the exponential decay considering dimensions other than the vertical dimension as suggested in the previous two references was attempted for the ten roadway configurations. The modification of Equation 3.3-1 utilizes the radial distance, ρ, in place of the vertical distance z. The mathematical equation describing the decrease in concentration is of the form:

$$C = CO_x \; e^{-a\rho} \qquad 3.3\text{-}2$$

where:

$$CO_x = \frac{M\dot{N}}{aW\left(D + \frac{V}{a}\right)} \qquad 3.3\text{-}3$$

ρ = Radial distance between source and receptor

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(1) Georgii, H.W., Busch, E., Weber, E., "Investigation of the Time and Space Distribution of Carbon Monoxide Emission Concentrations in Frankfurt AM Main," Report of the Institute for Meteorology and Geophysics of Frankfurt AM Main University, No. 11.

(2) Sontowski, J.F. and Dworetzky, L.H., "Transport of Traffic Generated Carbon Monoxide in Long City Streets," GE TIS 70SD236 (1970)

3.3.1 Superposition Method

It is assumed that any given roadway can be divided into independent line sources as represented in Figure 3.3-1 and each probe located at the roadway measures the concentration from its immediate line source plus the concentration emanating from the other (x-1) line sources. Further, it is assumed that the decrease in concentration from each probe location follows Equation 3.3-2. As a first approximation the effects of wind are implicitly stated in the coefficient, CO_x, as shown in Equation 3.3-3. This is somewhat justified since all of the computation will be made on concentration data that has been averaged over a minimum of 14 days, and provided CO_x is defined close to the roadway where vehicular induced turbulence predominates as opposed to wind induced turbulence.

CO_x is defined only for those probes located at the exhaust plane level which measure the highest concentration. These were located 3' off the roadway for all sites excepting the Viaduct site. Therefore, the concentration measured at any 3' probe when the cross roadway diffusion has been properly accounted for may be expressed by a set of linear equations which expressed in matrix algebra has the following form:

$$[C_x] = [\exp(-a\,\rho_{xj})]\,[CO_x] \qquad 3.3\text{-}4$$

where:

C_x = Concentration measured by a probe located 3' off the xth line source

ρ_{jx} = Distance between center of xth line and jth line source

CO_x = Concentration that would be measured at 3' if xth line source were unperturbed by concentrations diffusing over the other (x-1) source

a = Same constant as defined in Equation 3.3-1.

The value, CO_x, is defined as the unperturbed concentration resulting from the xth line source since the diffusion from the other (x-1) line sources has been now accounted for in Equation 3.3-4.

For the open cut or grade road sites the coefficient matrix is a 3 x 3 matrix since there were only 3 probes which measured the concentration of 3 line sources. It is quite impractical to measure the concentration of the middle line sources. When the model is applied to covered sites like Grand Central Parkway or Sutton Place, the method of images was used. This method considers the covering as a reflector, which means that there exist virtual sources on the other side of the reflector which must be considered. A figure depicting the application of this method to the Sutton Place site is presented in figure 3.3-2. Here the two additional sources are x_1' and x_2'

SUPERPOSITION METHOD FOR PREDICTING TRAFFIC GENERATED POLLUTION CONCENTRATIONS

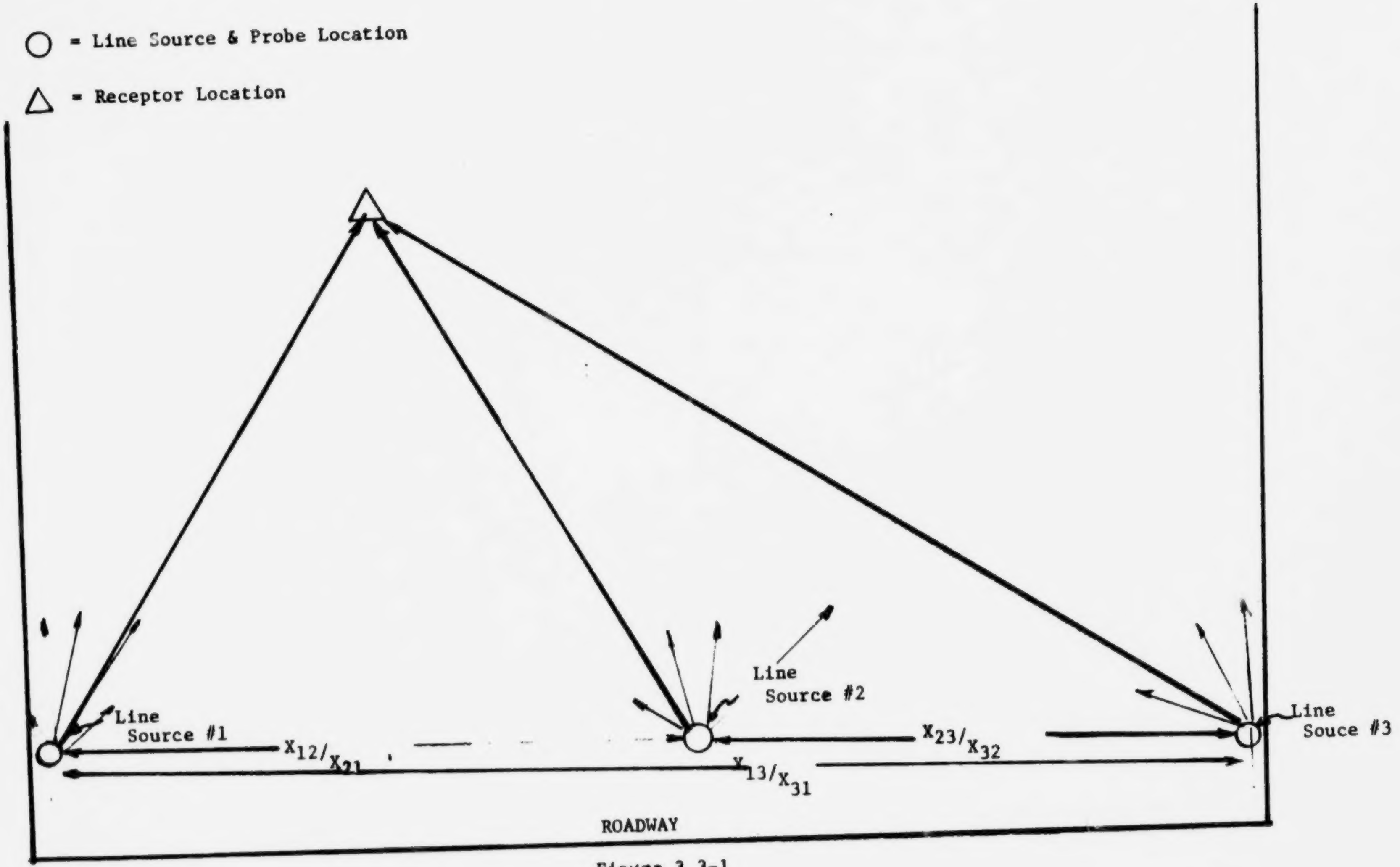

○ = Line Source & Probe Location
△ = Receptor Location
Line Source #1
Line Source #2
Line Souce #3
X_{12}/X_{21}
X_{23}/X_{32}
X_{13}/X_{31}
ROADWAY

Figure 3.3-1

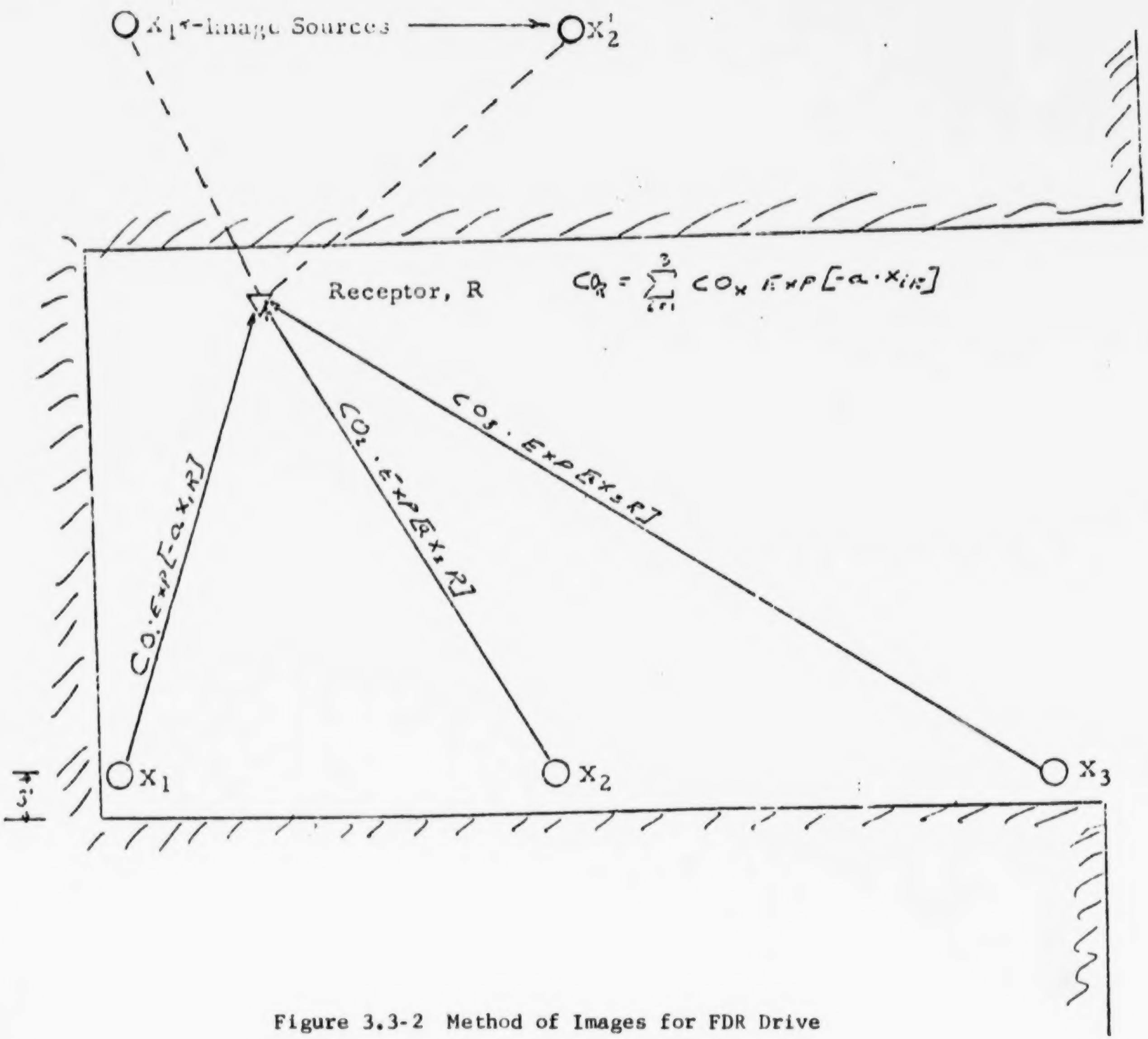

X_1 ←Image Sources → X_2'
Receptor, R
$CO_R = \sum_{i=1}^{3} CO_x \, EXP[-a \cdot x_{iR}]$
$CO_1 \cdot EXP[-a \, x_1 R]$
$CO_2 \cdot EXP[a \, x_2 R]$
$CO_3 \cdot EXP[a \, x_3 R]$
X_1
X_2
X_3
$\vdash 5 \dashv$

Figure 3.3-2 Method of Images for FDR Drive

which are mirror images of x_1 and x_2, respectively. For this particular site the coefficient matrix becomes a 5 x 5 matrix. It was also found, for covered sites, that some adjustments must be made in the decay constant, a, to provide an adequate representation of the concentrations measured.

The model was further generalized by defining the Vehicular Pollution factor, ϕ, by dividing the unperturbed concentration, CO_x, by the traffic flow rate in the immediate vicinity of the probe location.

The vehicular pollution factor, ϕ,

$$\phi = \frac{CO_x}{\dot{N}} \qquad 3.3\text{-}5$$

For eight of the configurations evaluated was found that shows a strong linear relation with traffic speed (correlation of .81) as shown by figure 3.3-3. The viaduct site exhibited pronounced meteorological effects which resulted in the two lower points to the extreme left in the figure. The low velocity points in the lower right hand is data collected in a city street. Data from the tunnel sites was not included in figure 3.3-3.

The linear relation between and traffic speed was found to be:

$$\phi_i = [\ -0.51\ (T_i) + 26.9]\ x\ 10^{-3} \qquad 3.3\text{-}6$$

for T: 15 mph $\leq$ T $\leq$ 49 mph

ϕ_i = Apparent emission factor $\frac{(PPM\text{-}Hr)}{veh}$

T_i = Average Traffic Speed in lane i

It is seen from Equation 3.3-6 that traffic speed is the predominant factor and that the ranking of the sites must be based upon traffic speed, as well as site configuration. Stated in other terms, the line source strength decreases with increasing automobile speed due to the measure in vehicular induced turbulence and engine efficiency.

Using Equation 3.3-6 and the total traffic volume it now is possible to compute the concentration in and around a given expressway by super imposing the various line sources as given below:

$$[CO]_R = \sum_{i=1}^{S} \phi_i \ N_i \ \exp\ [-a\ \rho\ iR] \qquad 3.3\text{-}7$$

where

$[CO]_R$ = Carbon Monoxide concentration at receptor, R

ϕ_i = Vehicular pollution factor for line source, i, from Equation 3.3-6 $\frac{(PPM\text{-}Hr)}{veh}$

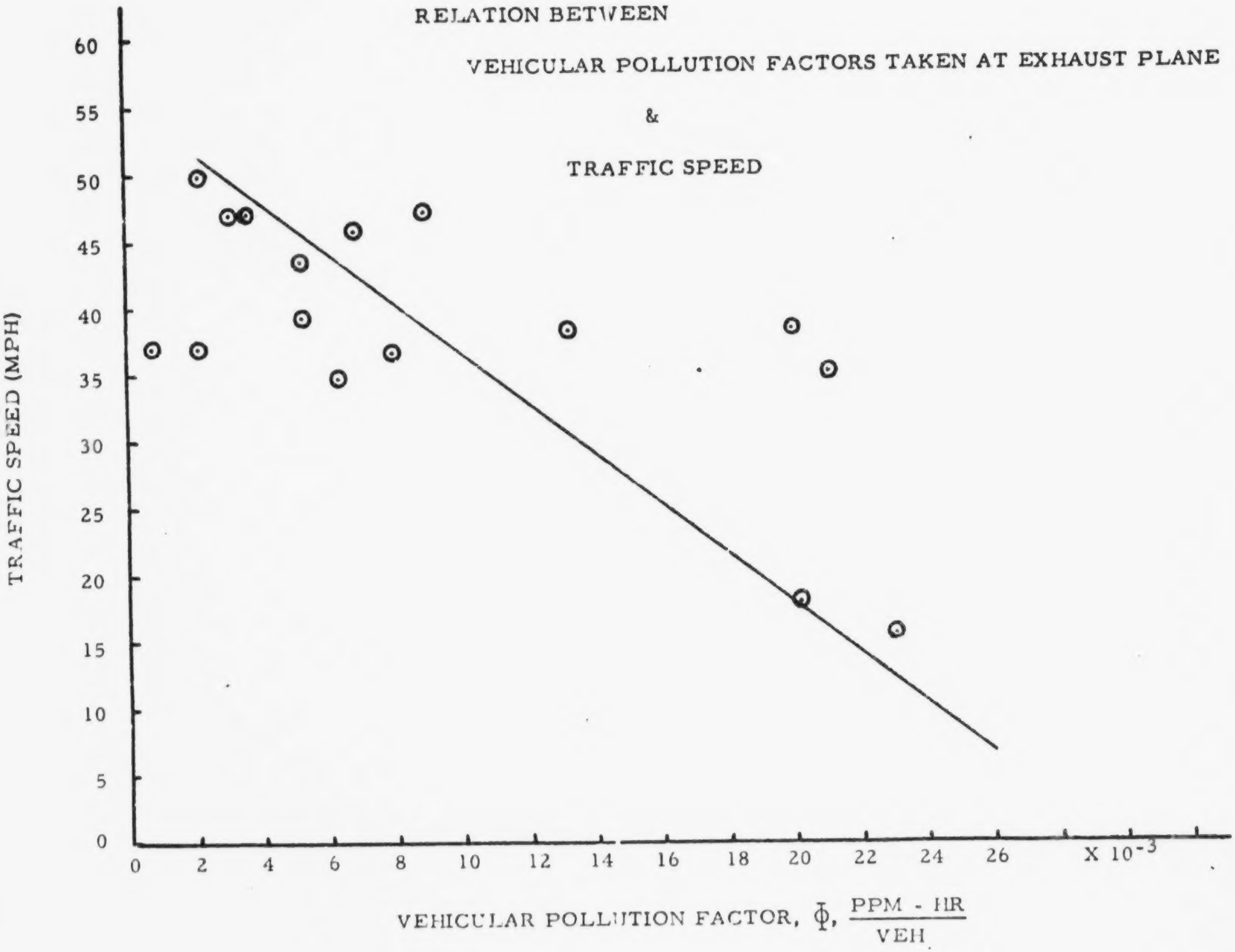

RELATION BETWEEN
VEHICULAR POLLUTION FACTORS TAKEN AT EXHAUST PLANE
&
TRAFFIC SPEED
TRAFFIC SPEED (MPH)
60
55
50
45
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
X 10^-3
VEHICULAR POLLUTION FACTOR, Φ, PPM - HR / VEH

Figure 3.3-3

N_i = Traffic flow rate from roadway source, i,

a = Empirical constant derived from New York City data and reference 1. (.02 ft^{-1} for open sites and .045 ft^{-1} for covered sites)

ρiR = Radial distance between roadway source, i., and receptor, R

i = Roadway source which may be defined by direction, i.e., one roadway may be considered as being two sources moving in opposite directions.

S = Total number of sources

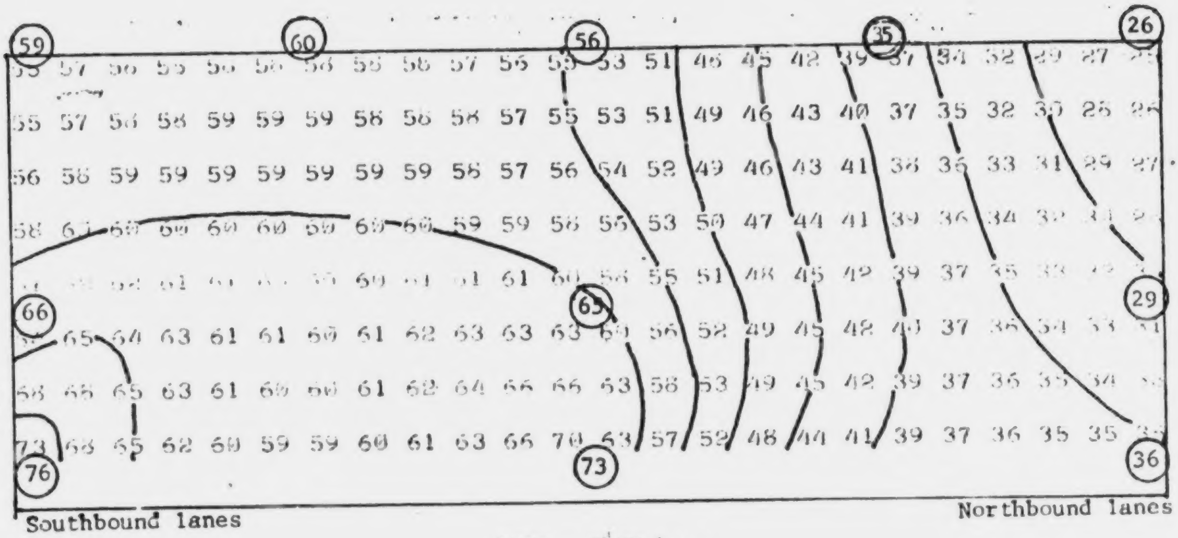
It is felt that the particular reason why the high degree of linear correlation between traffic speed and ϕ exists is due directly to the application of Equation 3.3-4, where the cross roadway diffusion is accounted for in a gross sense. Consequently, the concentration measured can be directly related to the traffic volumes and speed in the immediate vicinity of the measurement. The Vehicular Pollution factor, ϕ_i, may now be used as the source strength, Q, in area models to project the concentrations to longer distances than those evaluated in this study. One of the particular weaknesses of Equation 3.3-7 is when the distance, ρiR, becomes large and the concentrations approach the background. Certain model modifications are possible but were not attempted in this study.

3.3.2 Model Validation

The model was utilized to define the concentration isopleths over the test roadway by programming Equation 3.3-7 on a desk side computer and calculating the concentration in discrete grid points over the roadway. Although not shown in the following figures, the model was used to project the concentration to the zone of the nearest receptor. Figures 3.3-4 through 3.3-16 present the comparison between the measured and predicted concentration at each site for selected hours during the course of the day. The hours chosen represent those periods of peak traffic volume.

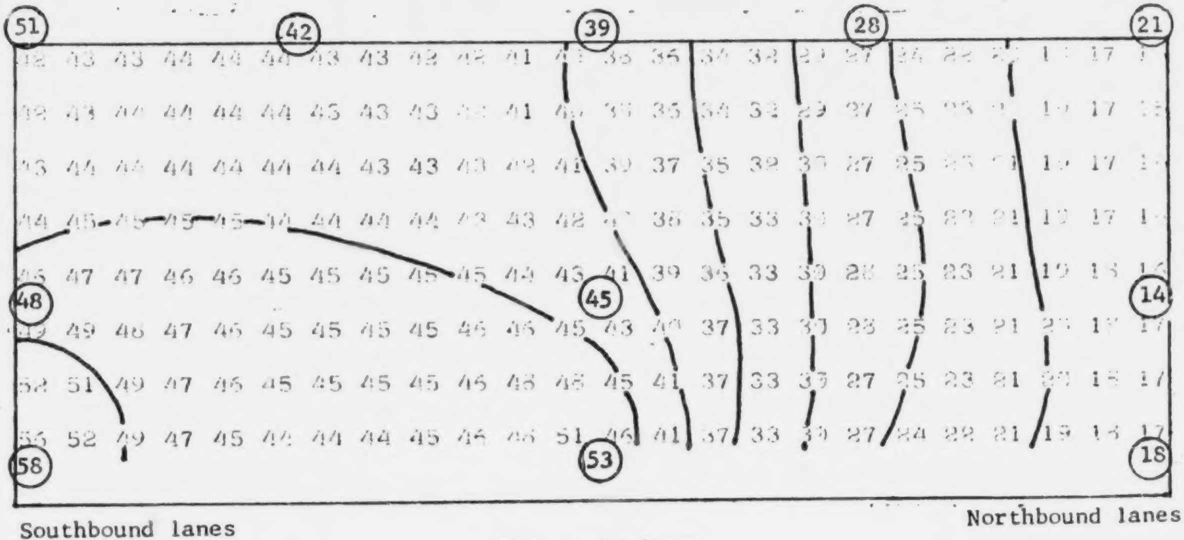
The model has the capability of distinguishing the influence of varying traffic speed and volume in each direction as shown in Figure 3.3-7, where the major flow during the periods between 0800 - 0900 hours is Manhattan or Queens bound and, between 1600 - 1700 hours, is homeward bound toward Brooklyn. In figure 3.3-4 the ventilation characteristics of the covered on top - open on one side site is demonstrated. The contours for this covered on top - open at side site correctly show the concentration gradient vector pointing in the direction of the open side. The effect of a cover over the roadway is shown in figures 3.3-8 and 3.3-9 for the unventilated tunnel where the anticipated high CO concentration appear along the walls and ceiling.

Model validation was not as good for the two sites which possessed the highest ventilation namely, the Grade road and the Viaduct sites. It is seen



0700 - 0800 hours

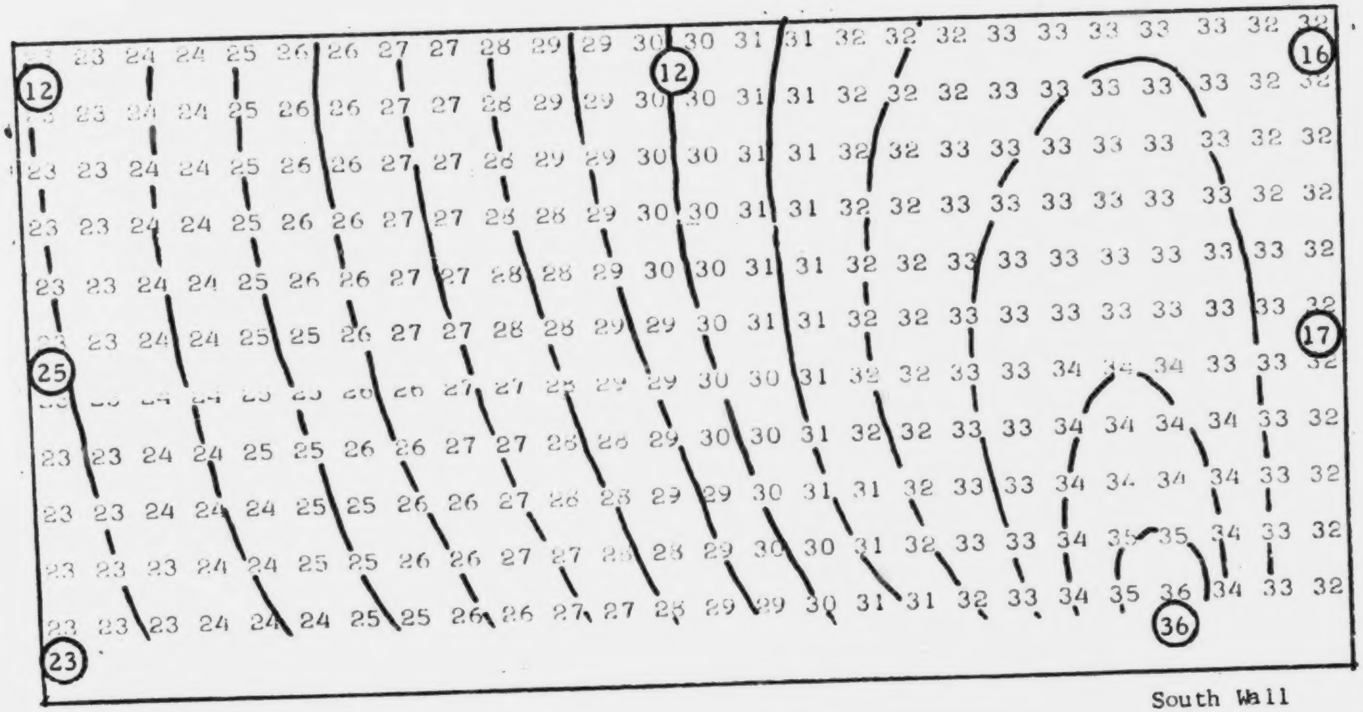
Reproduced from best available copy.



1600 - 1700 hours

Calculated Values - Decay Constant = -.045 - Grid Size = 3 ft. - Contour interval=5PPM
Measured values included in 0

Figure 3.3-4 Measured & Calculated Mean Carbon Monoxide Contours -
F.D.R. Drive at Sutton Place Covered on top - open at side



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23	23	24	24	25	26	26	27	27	28	29	29	30	30	31	31	32	32	33	33	33	33	33	33	32	32
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23	23	24	24	25	25	26	26	27	27	28	29	29	30	30	31	32	32	33	33	34	34	34	33	33	32
23	23	24	24	25	25	26	26	27	27	28	28	29	30	30	31	32	32	33	33	34	34	34	34	33	32
23	23	24	24	24	25	25	26	26	27	28	28	29	29	30	31	31	32	33	33	34	34	34	34	33	32
23	23	23	24	24	25	25	26	26	27	27	28	28	29	30	30	31	32	33	33	34	35	35	34	33	32
23	23	23	24	24	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	34	35	36	34	33	32

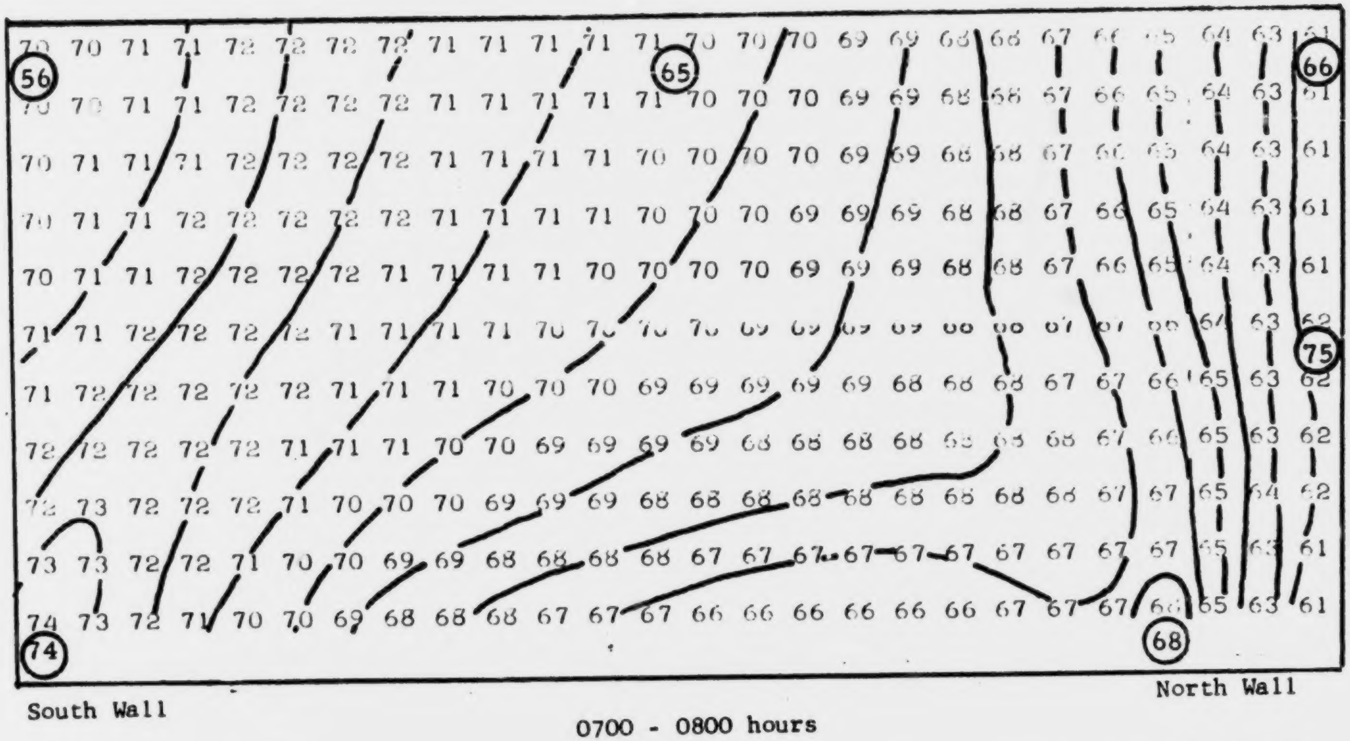
North Wall

South Wall

0700 - 0800 hours

Calculated Values - Decay Constant = -.045 - Grid Size = 1 foot - Contour Interval = 1 PPM
Measured Values included in O

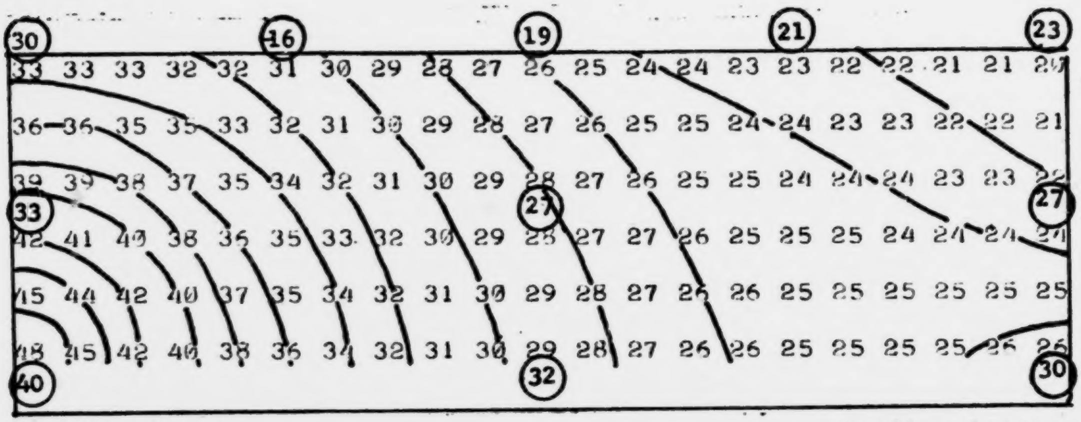
Figure 3.3-5 Measured and Calculated Mean Carbon Monoxide Contours Brooklyn Battery Tunnel, Manhattan Bound - Long Tunnel



0700 - 0800 hours

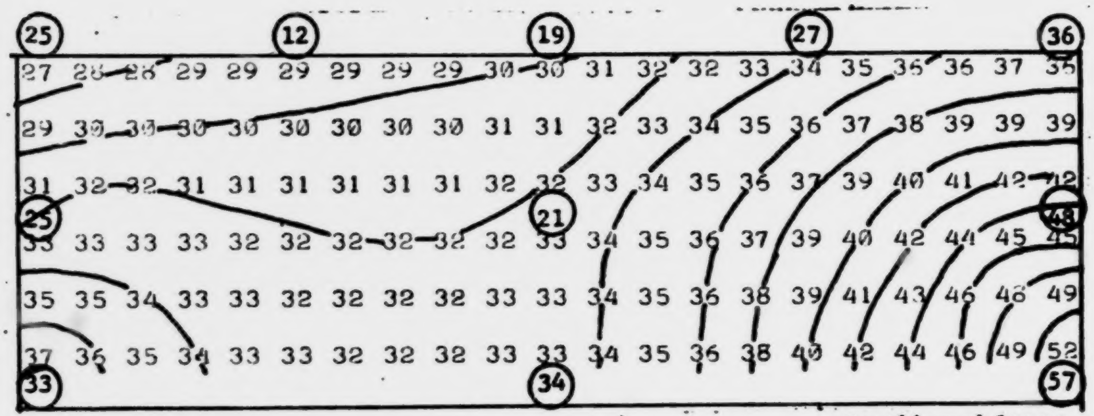
Calculated Values - Decay Constant = -.045 - Grid Size = 1 foot - Contour Interval = 1 PPM
Measured Values Included in O

Figure 3.3-6 Measured and Calculated Mean Carbon Monoxide Contours Brooklyn Battery Tunnel, Brooklyn Bound - Long Tunnel



Northbound Lanes Southbound Lanes

0800 - 0900 hours

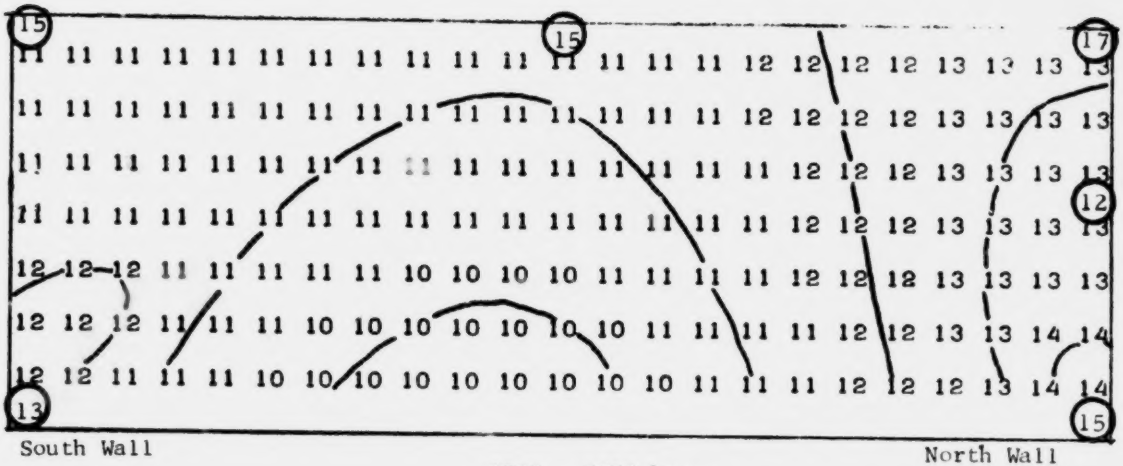


Northbound Lanes Southbound Lanes

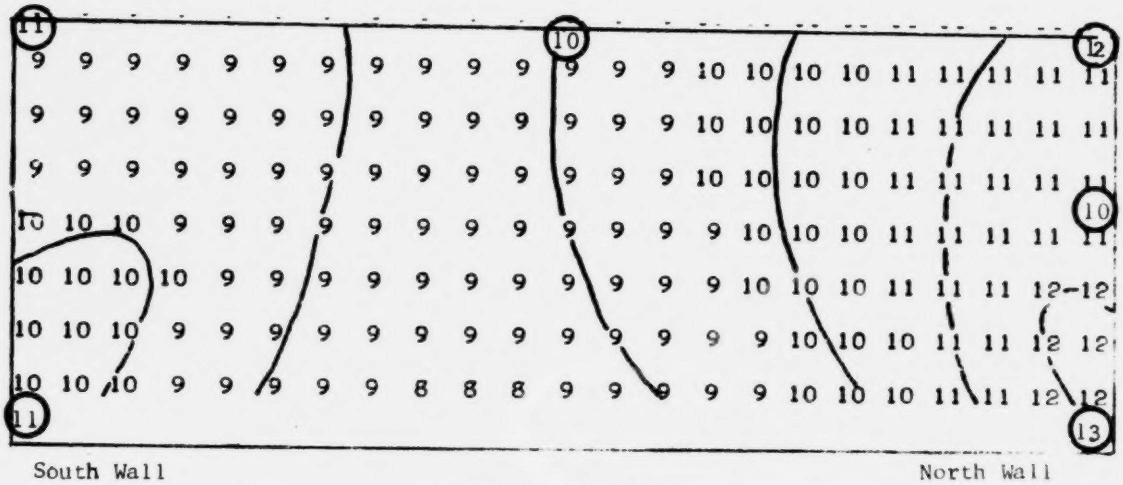
1600 - 1700 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 4 feet - Contour Interval = 2 PPM Measured Values enclosed in O

Figure 3.3-7 Measured & Calculated Carbon Monoxide Contours Brooklyn Queens Expressway at Hicks Street - Shallow Cut



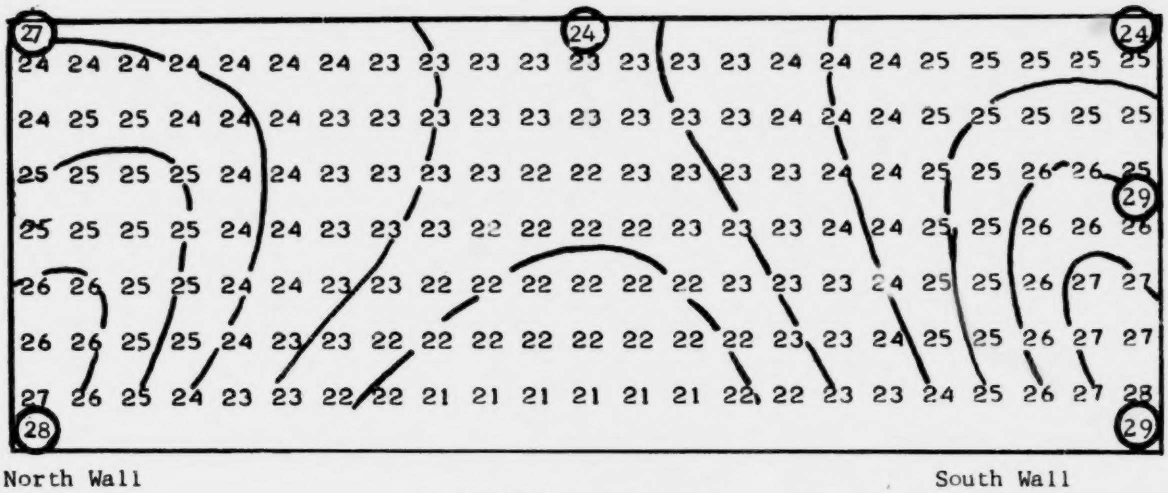
0700 - 0800 hours



1200 - 1300 hours

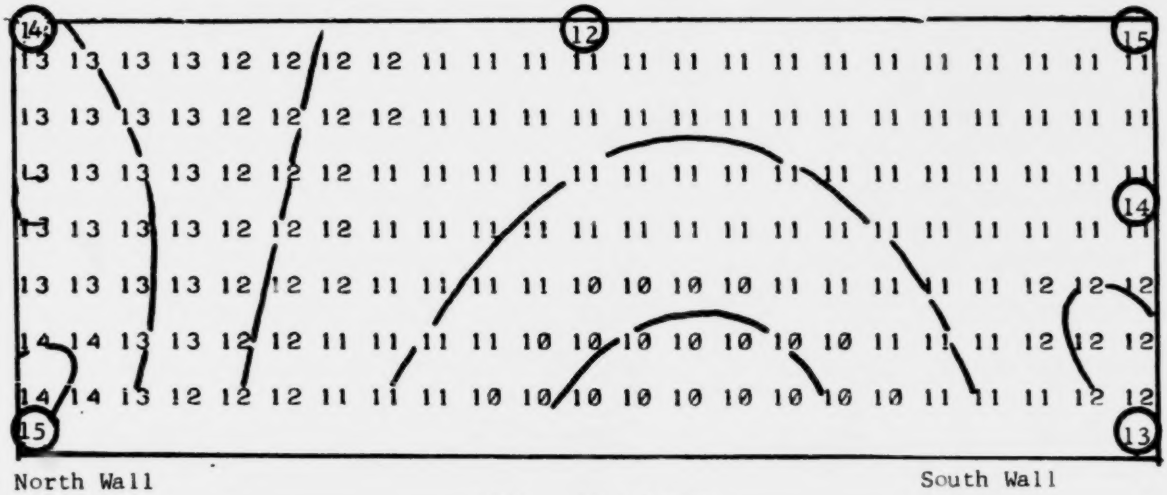
Calculated Values - Decay Constant = -.045 - Grid Size = 2 feet - Contour Interval = 1 PPM - Mean Measured Values Included in O

Figure 3.3-8 Measured & Calculated Carbon Monoxide Contours
Cross Bronx Expressway at Grant Circle, Eastbound Tunnel,
Short Tunnel



24	24	24	24	24	24	24	23	23	23	23	23	23	23	23	24	24	24	25	25	25	25	25
24	25	25	24	24	24	23	23	23	23	23	23	23	23	23	24	24	24	25	25	25	25	25
25	25	25	25	24	24	23	23	23	23	22	22	23	23	23	23	24	24	25	25	26	26	25
25	25	25	25	24	24	23	23	23	22	22	22	22	23	23	23	24	24	25	25	26	26	26
26	26	25	25	24	24	23	23	22	22	22	22	22	22	23	23	23	24	25	25	26	27	27
26	26	25	25	24	23	23	22	22	22	22	22	22	22	22	23	23	24	25	25	26	27	27
27	26	25	24	23	23	22	22	21	21	21	21	21	21	22	22	23	23	24	25	26	27	28

1600 - 1700 hours



13	13	13	13	12	12	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
13	13	13	13	12	12	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
13	13	13	13	12	12	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
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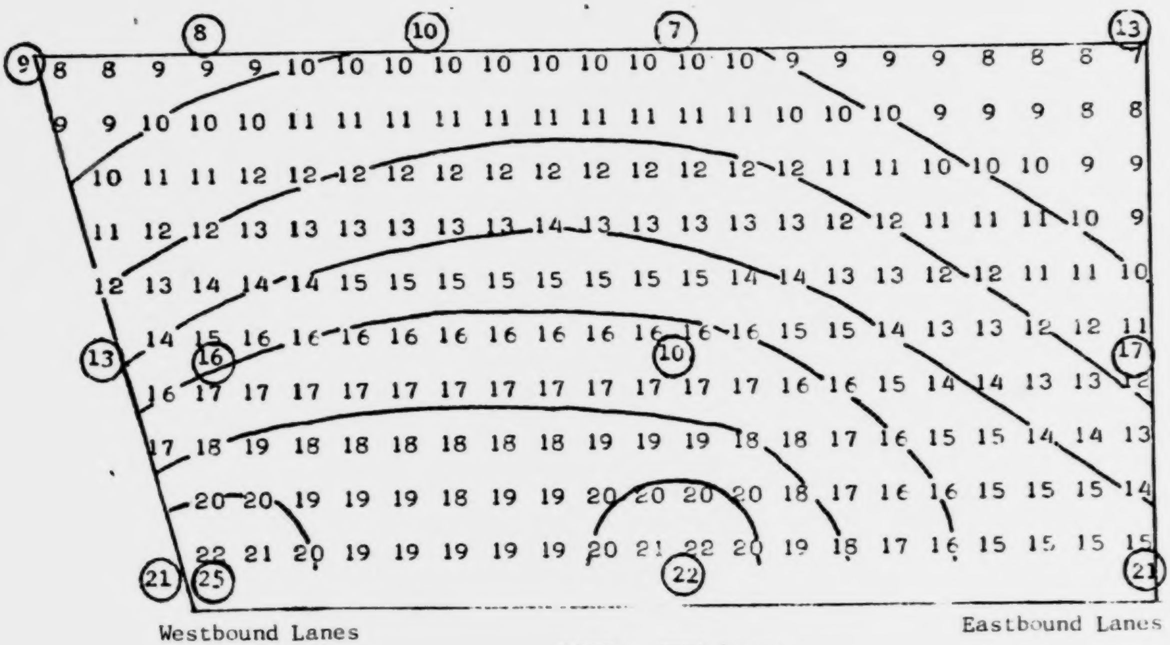
14	14	13	13	12	12	11	11	11	11	10	10	10	10	10	10	10	11	11	11	12	12	12
14	14	13	12	12	12	11	11	11	10	10	10	10	10	10	10	10	10	11	11	11	12	12

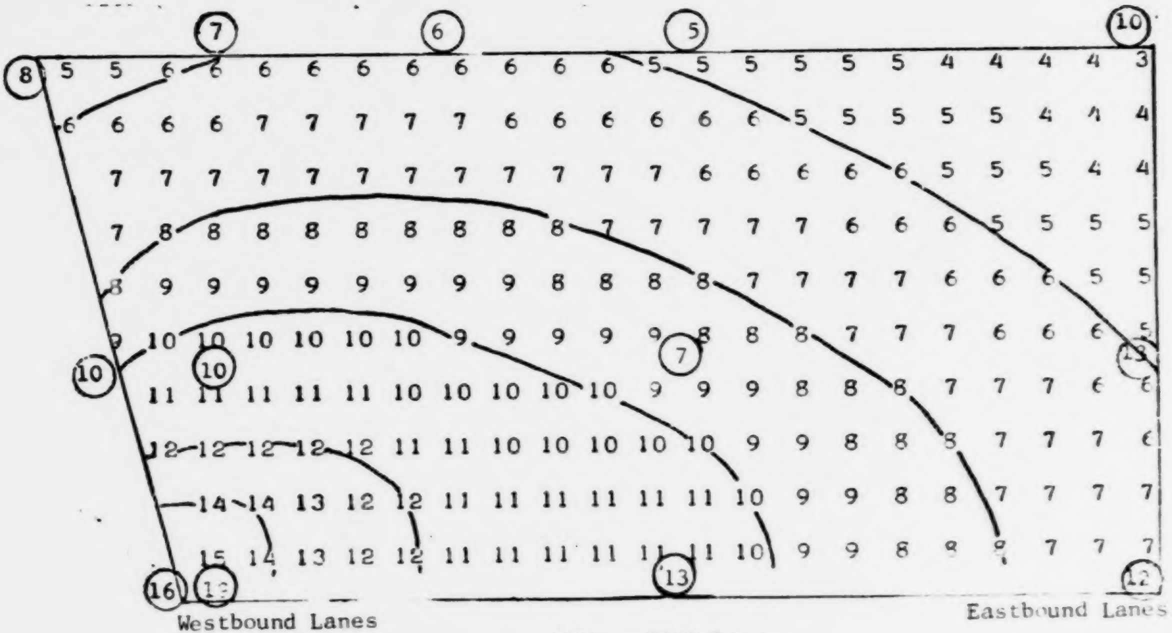
2000 - 2100 hours

Calculated Values - Decay Constant = -.045 - Grid Size = 2 ft. - Contour Interval = 1 PPM Mean Measured Values included in O

Figure 3.3-9 Measured & Calculated Carbon Monoxide Contours, Cross Bronx Expressway at Grant Circle, Westbound Tunnel - Short Tunnel



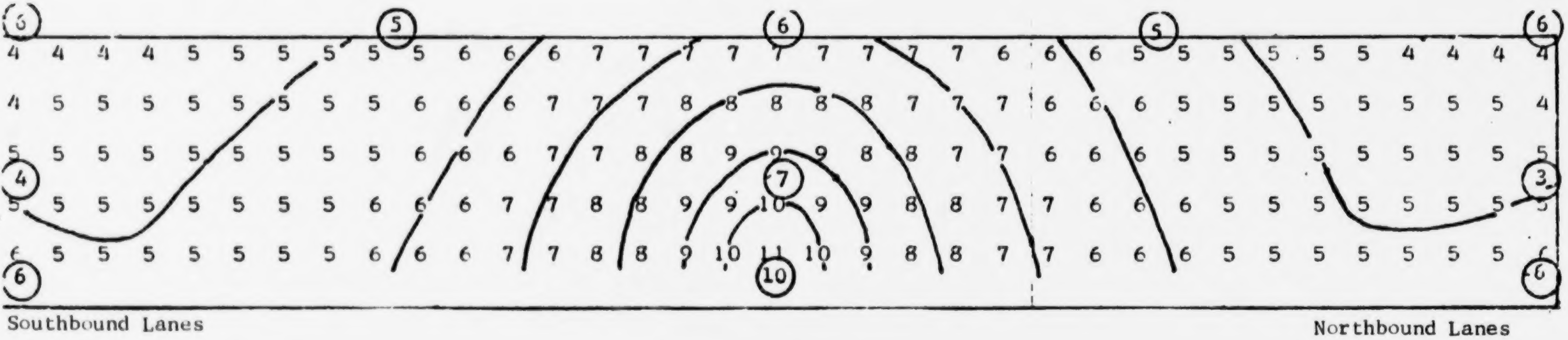
1600 - 1700 hours



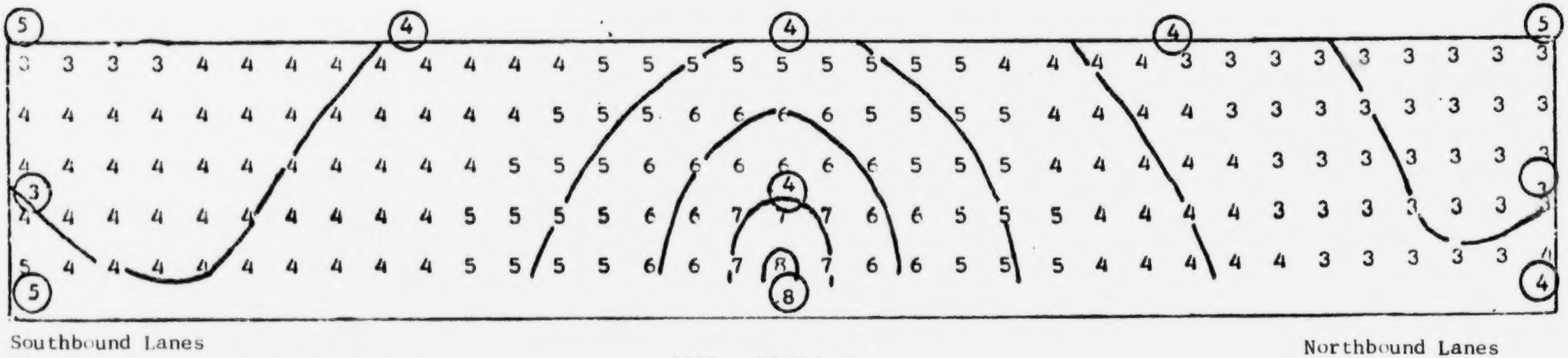
2000 - 2100 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 6 ft. - Contour Interval = 2 PPM - Measured Values enclosed in O

Figure 3.3-10 Measured & Calculated Mean Carbon Monoxide Contours Cross Bronx Expressway at Nelson & Jessup Sts. - Deep Cut



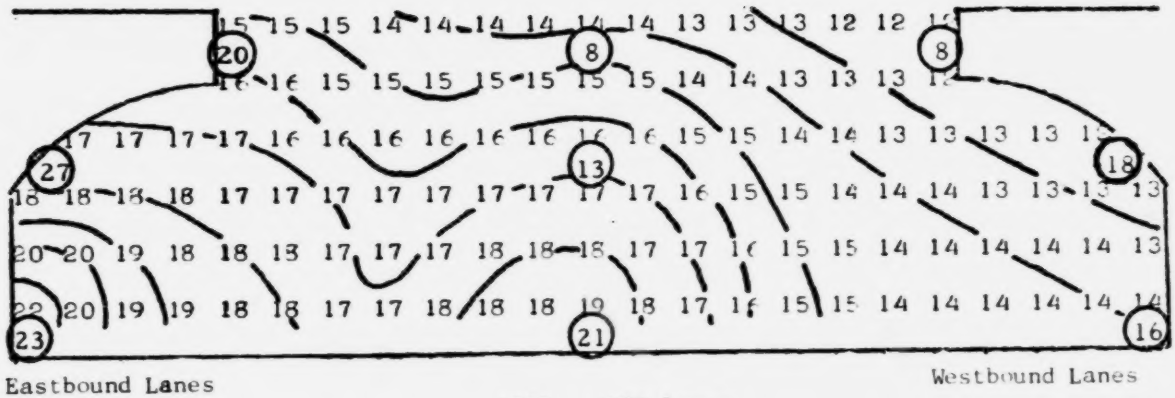
0700 - 0800 hours



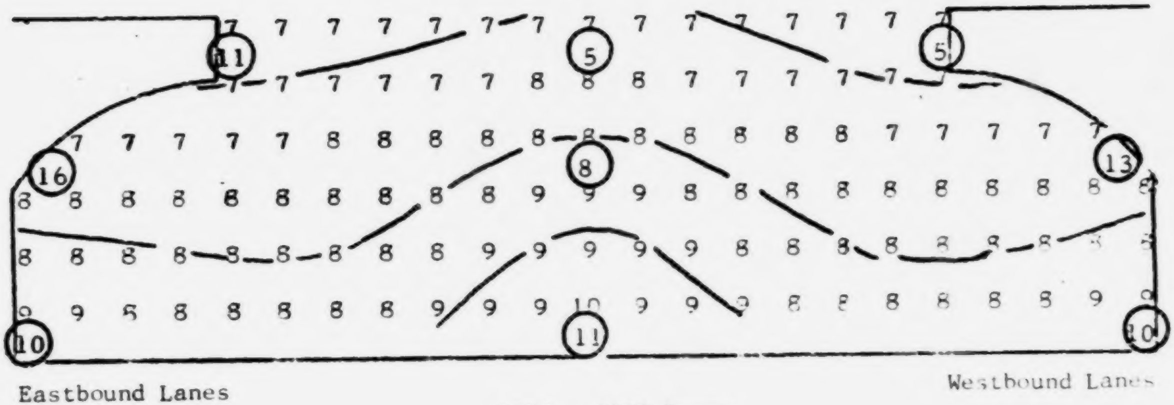
1200 - 1300 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 5 feet - Contour Interval = 1 PPM - Mean Measured Values enclosed in O

Figure 3.3-11 Measured & Calculated Mean Carbon Monoxide Contours; Bruckner Expressway near White Plains Road - Grade Road



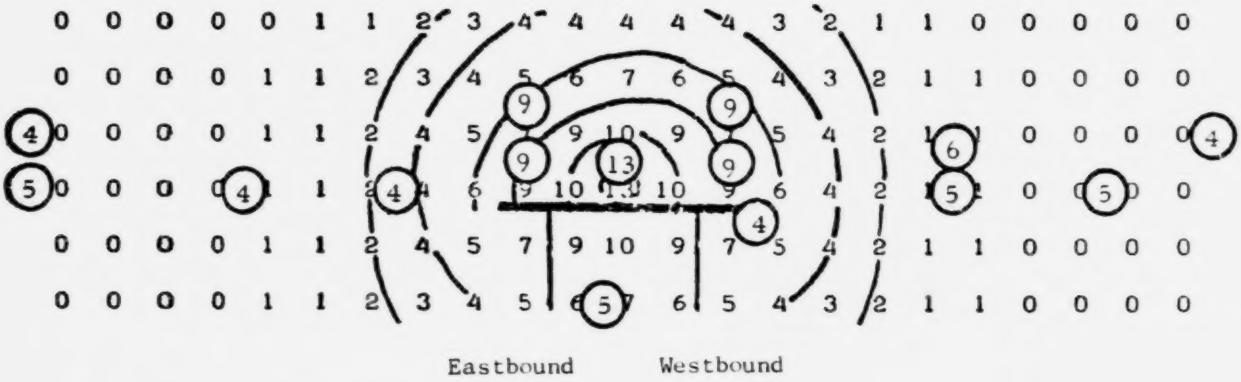
1700 - 1800 hours



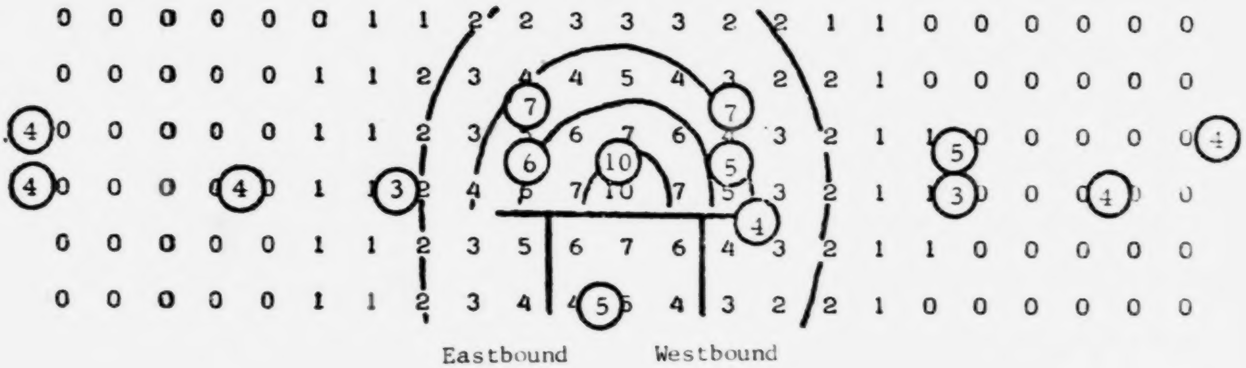
2000 - 2100 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 5 feet - Contour Interval = 1 PPM   Mean Measured Values Enclosed in O

Figure 3.3-12 Measured & Calculated Mean Carbon Monoxide Contours Grand Central Parkway at Parsons Boulevard - Cantilever



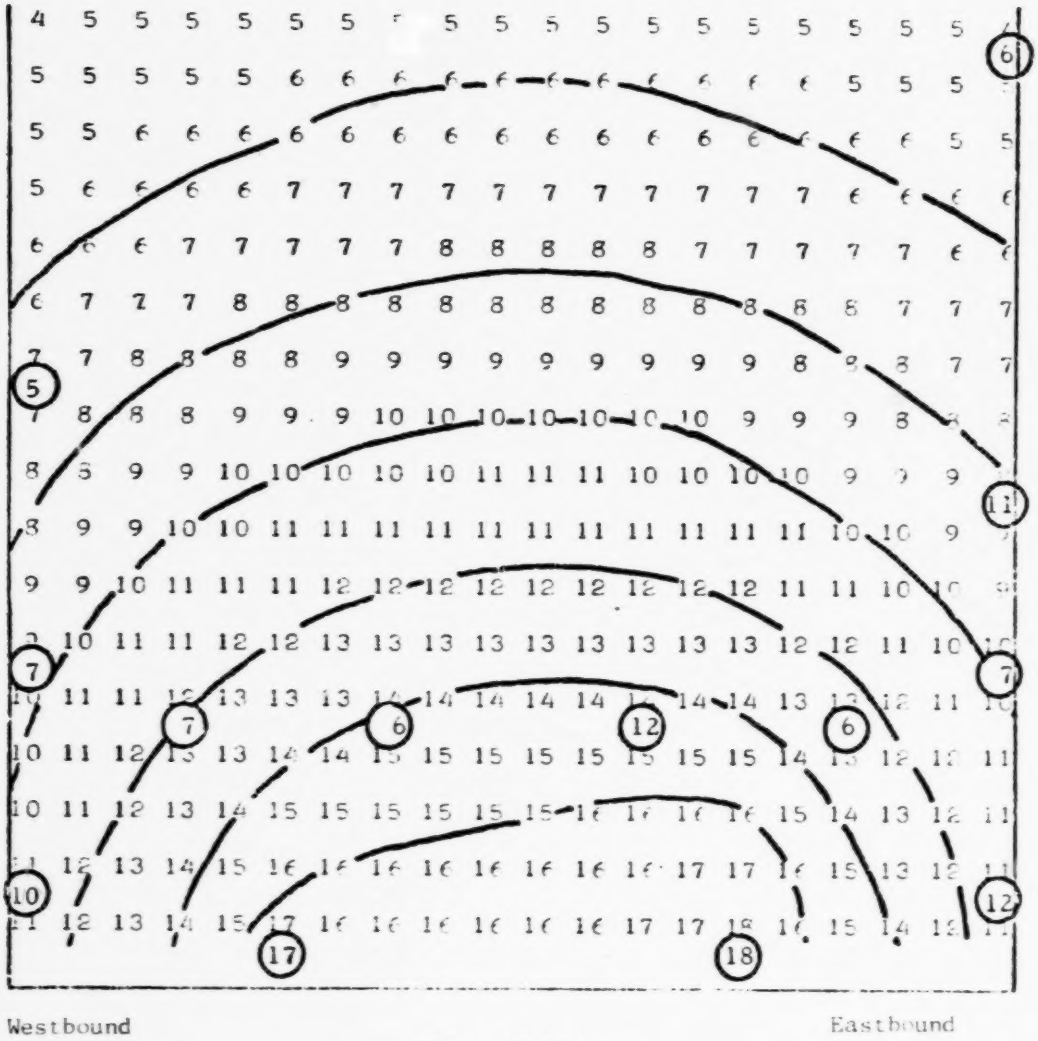
0700 - 0800 hours



2000 - 2100 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 20 feet - Contour Interval = 2 PPM Mean Measured Values Enclosed in O

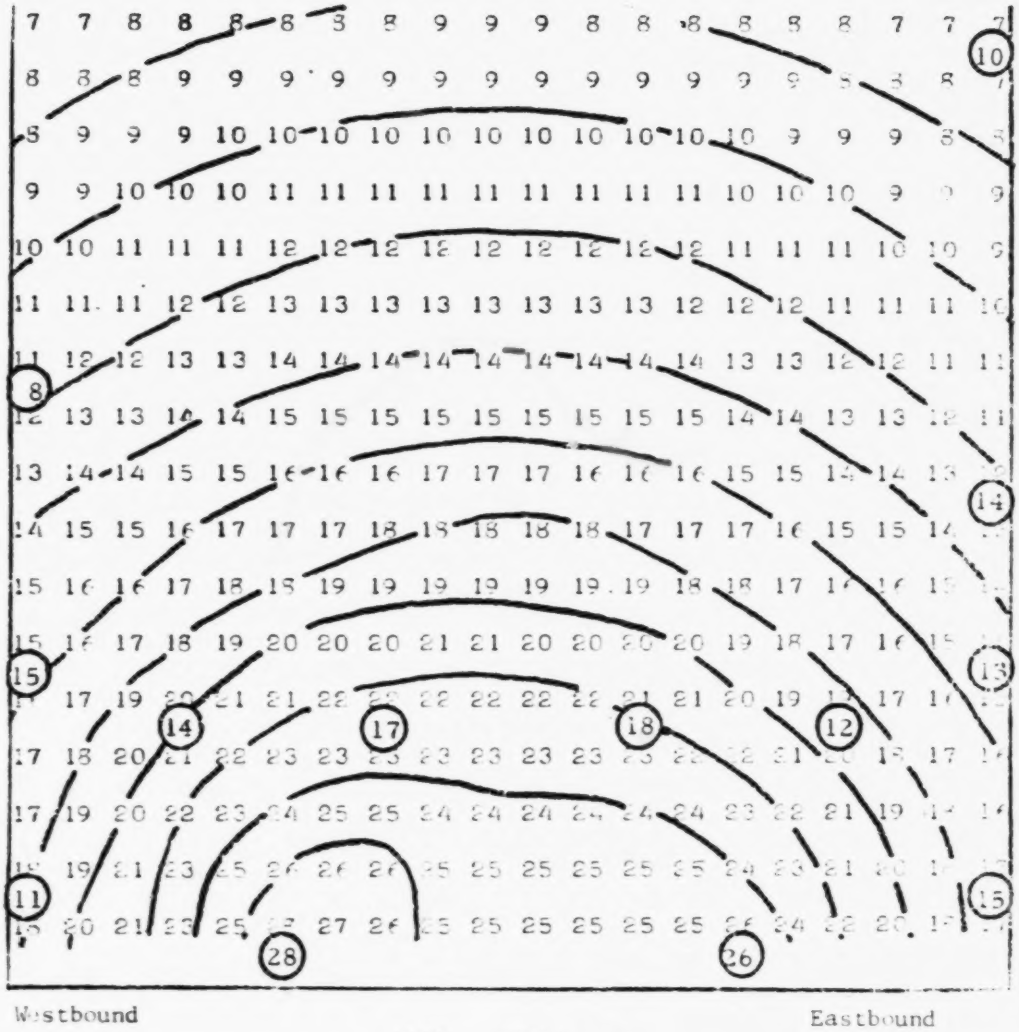
Figure 3.3-13 Measured & Calculated Mean Carbon Monoxide Contours Brooklyn Queens Expressway at Park & Navy Streets - Viaduct



0700 - 0800 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 5 feet - Contour Interval = 2 PPM   Mean Measured Values Enclosed in O

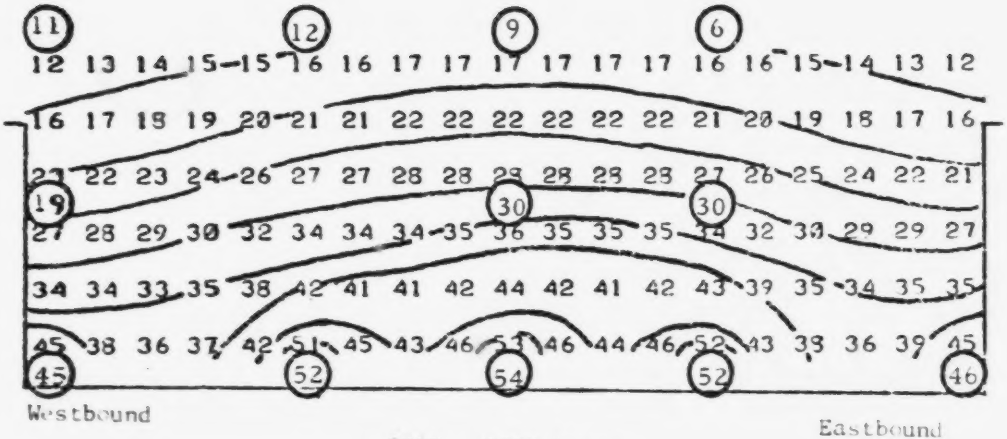
Figure 3.3-14 Measured & Calculated Mean Carbon Monoxide Contours
Canal Street between Church & Mercer Streets - City Street



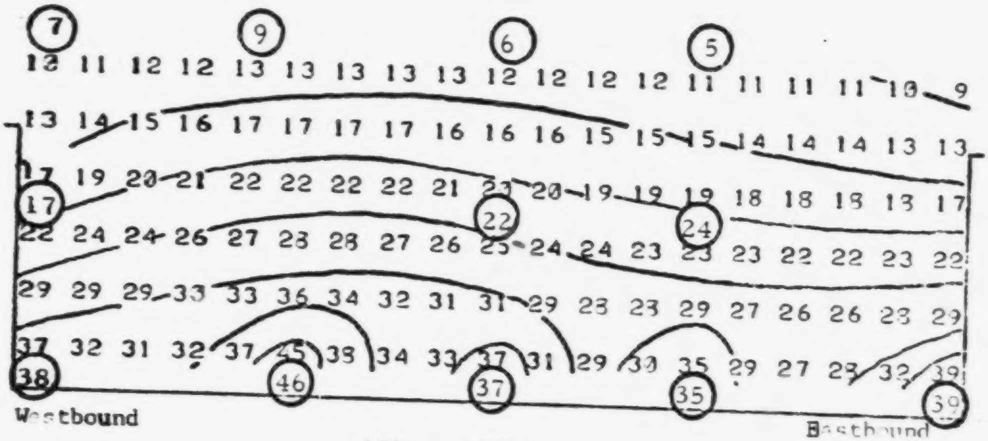
1600 - 1700 hours

Calculated Values - Decay Constant = -.02 - Grid Size = 5 feet - Contour Interval = 2 PPM Mean Measured Values Enclosed in O

Figure 3.3-15 Measured & Calculated Mean Carbon Monoxide Contours Canal Street between Church and Mercer Streets - City Street


11 12 9 6
12 13 14 15 15 16 16 17 17 17 17 17 17 16 16 15 14 13 12
16 17 18 19 20 21 21 22 22 22 22 22 22 21 20 19 18 17 16
22 22 23 24 26 27 27 28 28 28 28 28 28 27 26 25 24 22 21
19 30 30
27 28 29 30 32 34 34 34 35 36 35 35 35 34 32 30 29 29 27
34 34 33 35 38 42 41 41 42 44 42 41 42 43 39 35 34 35 35
45 38 36 37 42 51 45 43 46 53 46 44 46 52 43 38 36 39 45
45 52 54 52 46
Westbound
Eastbound

0700 - 0800 hours


7 9 6 5
12 11 12 12 13 13 13 13 13 12 12 12 12 11 11 11 11 10 9
13 14 15 16 17 17 17 17 16 16 16 15 15 15 14 14 14 13 13
17 19 20 21 22 22 22 22 21 21 20 19 19 19 18 18 18 18 17
17 22 24
22 24 24 26 27 28 28 27 26 25 24 24 23 23 23 22 22 23 22
29 29 29 33 33 36 34 32 31 31 29 28 28 29 27 26 26 28 29
37 32 31 32 37 45 38 34 33 37 31 29 30 35 29 27 28 32 39
38 46 37 35 39
Westbound
Eastbound

1200 - 1300 hours

Calculated Values - Decay Constant = -.032 - Grid Size = 10 feet - Contour Interval = 5 PPM Mean Measured Values Enclosed in O

Figure 3.3-16 Measured & Calculated Mean Carbon Monoxide Contours Trans-Manhattan Expressway at George Washington Plaza - Intermittent Span

for these sites (figures 3.3-11 and 3.3-13) that the levels measured are very near background, which is not accounted for in the model. Also, the measurement accuracy is questionable at these low levels due to relative humidity effects and calibration accuracy. To measure these small gradients instrumentation modifications are necessary. (Ref. to Intertech Corp. Operators Manual CG-G57 3e pg. 13, 1960).

Similarly, model validation was not as good for the long tunnel configuration due in part to the small differences in the concentration gradient and the forced ventilation of the tunnel. Generally, the gradient vector points to the walls, which suggests the major air flow in the tunnel is in the direction of vehicular travel. During the course of probe installation for both tunnels, this was found to be the case. No meteorological gear was installed in the roof of the tunnel to verify general flow in the tunnel. The so called "piston" effect for tunnels suggests that the assumption of a constant line source is not a valid assumption. Data collected for the long tunnel shows pronounced increase in concentration for those periods of time of counter current traffic. However, no data was obtained to prove the existence of a non-uniform line source. If the line source is non-uniform, model modification is necessary as perhaps an another model should be developed for the covered forced ventilated configuration.

For all of the open sites, the model was found to be quite general since a constant decay constant of .02 ft^{-1} was used. Further, the model was found not to be configuration limited due to the high influence of traffic speed except for those cases of unusual high ventilation.

Considering the general nature of the model, the comparisons between measured and predicted data are remarkably good and should have wide application in defining urban and transportation planning parameters in meeting the 1970 Air Quality Standards.

4.0 SITE DESCRIPTION AND MEASUREMENTS

4.1 Summary Tables

4.1.1 Pollutants

Table 4-1 presents the quantity and quality of data collected at each site. The overall summary results of the study are presented in Section 1. The majority of the data collected was carbon monoxide data since there were 8 instruments operating simultaneously at each site evaluated.

One Hydrocarbon analyzer, two High Volume samplers, one Tape sampler and two MRI vector vane metorological sensors were used for the other data. All of the above data was collected for 24 hours over the time durations shown in Table. 4-1 The data is tabulated in the Appendices.

4.1.2 Traffic Characteristics

The Diurnal curves for traffic volumes are shown in Section 2.1. Table 2.3-1 gives data on speeds, total volumes, and hourly volumes for traffic at each site.

All traffic measurements were gathered by the New York State Transportation Administration in their specially equipped trailer. Pneumatic tubes were placed on the roadway in each traffic lane, and by measuring the time lapse between tube depressions as well as the number of depressions, both the speeds and traffic volumes were determined.

As expected, the largest traffic volumes were in the express roads - Trans Manhattan Expressway, Cross Bronx Expressway, Grand Central Parkway, and the Brooklyn-Queens Expressway. These roads also registered fairly high average speeds - about 45 miles per hour - with the exception of the Trans Manhattan Expressway because of the merging traffic patterns for the George Washington Bridge approach and exits. City street speeds and volumes (Canal Street) predictably were lowest of all sites. Average peak hourly traffic volumes were greatest for the Trans Manhattan Expressway and Grand Central Parkway, reflecting interstate road travel and transport between Long Island and the Bronx and Manhattan respectively.

TABLE 4-1 - SUMMARY OF MONITORING ACTIVITY AT EACH SITE

Site	Number of Sampling Days									
	Carbon Monoxide Long Path Infra-red		Hydrocarbons Flame Ionization		Particulates High Volume Air Sampler		Particulates Tape Sampler		Meteorological Data	
	Week-days	Week-ends	Week-days	Week-ends	Week-days	Week-ends	Week-days	Week-ends	Week-days	Week-ends
Covered on Top-Open at Sides 54th & Sutton Place-FDR Drive	23	6	8	4	4	2	10	3	9	4
Long Tunnel Brooklyn-Battery Tunnel	7	3	0	0	2	1	0	0	0	0
Brooklyn-Queens Expressway at Hicks Street Shallow Cut	15	4	12	4	7	1	12	4	15	6
Short Tunnel Hugh Grant Circle	12	4	8	2	7	0	13	4	12	4
Deep Cut Nelson and Jessup	11	3	10	2	7	2	13	4	9	4
Grade Road Bruckner Expressway	11	4	11	4	4	2	16	6	11	4
Grand Central Parkway at Queens Hospital Cantilever Site	11	4	11	4	9	2	10	4	11	4
Brooklyn-Queens Expressway on Navy Street Viaduct Site	13	4	11	4	3	0	13	4	13	4
City Street Canal Street	11	4	9	2	3	0	10	4	12	4
Intermittent Span George Washington Bridge	17	6	17	6	10	3	6	2	14	6

4.2 Site Activity

4.2.1 Franklin D. Roosevelt Drive at Sutton Place

4.2.1.1 Site Description

In order to study the carbon monoxide profile within a cantilever covered roadway, a unique site configuration along Manhattan's Franklin D. Roosevelt Drive was selected to be the testing area. At this point along the Drive, a large apartment building was built directly over six lanes of traffic in such a way as to form a covered roadway open at one side. Through this structure (~ 3/8 miles long) flows a total of three northbound and three southbound traffic lanes. The outermost lane heading south is an exit lane which tends to slow down traffic in that direction. The counter flow lanes are separated by a 2' high medial barrier on which 2' x 2' support pillars are evenly spaced (~15' between pillars). Concrete pillars are also positioned along the open side of the structure but for all practical purposes that side is considered open. Fig. 4.2-1 shows the test location at the south end of the cantilever structure.

Frankling D. Roosevelt Drive carries approximately 98,000 cars per day. Average speed is 35 miles per hour. The northbound lanes carry 50,000 cars with an average weekday peak volume of 3,820. The southbound lanes carry 47,000 cars daily at a 3,370 average peak. No truck traffic is permitted.

There are no exhaust fans within the structure, the majority of the ventilation being provided by the open side. The site is isolated, in that all CO concentrations can be considered to have totally evolved from the traffic flowing to and from the site structure.

This site has two important features that make it interesting for evaluation. First, it is a cantilever covered roadway with one side open and secondly, people are living directly above the roadway where pollution levels may at times reach an unhealthy level.

4.2.1.2 Instrumentation Arrangement

The GE Air Pollution Van and the New York State Traffic Trailer were parked to the west of the structure at the corner of 54th Street and Sutton Place, approximately 15 feet above the surface of the test roadway. Figs. 4.2-2 and 4.2-3 show the locations of the trailers and the data sensors.

A total of 15 probes were installed to monitor the CO concentrations. Eleven probes were positioned ~70' within the structure in order to monitor a two dimensional CO profile perpendicular to the roadway. Three of these were located along the west wall, three at the medial barrier, and three along the open side. These probles were 3', 9', and 20' from the roadway. One probe was located 20' above the roadway in the center of each direction of traffic.

Three additional probles were positioned adjacent to the apartment building outside the structure at 12', 27', and 55' respectively from the sidewalk. One probe was located inside the apartment building at the 55' level. These four probes provided data on the indoor-outdoor CO relationship.

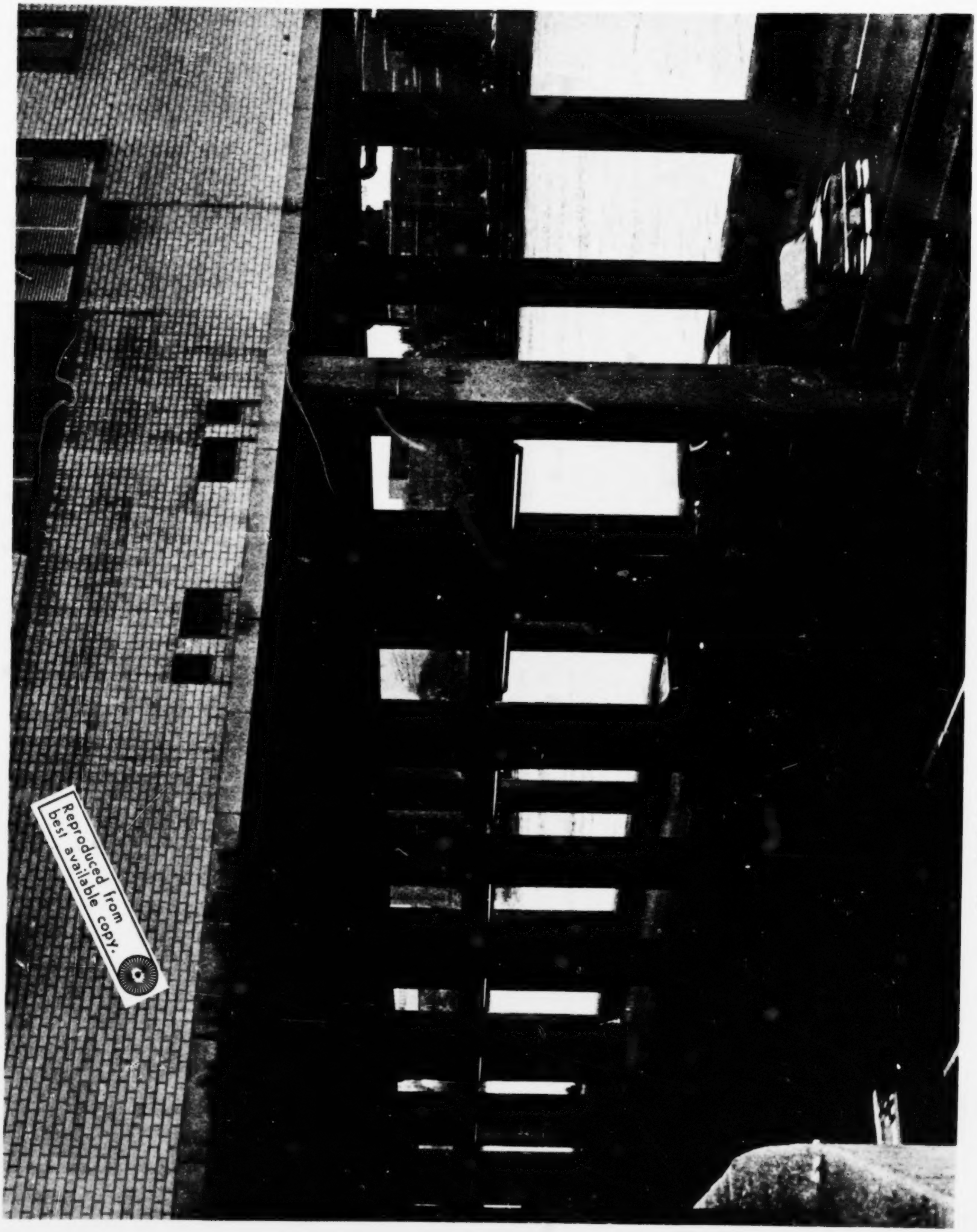


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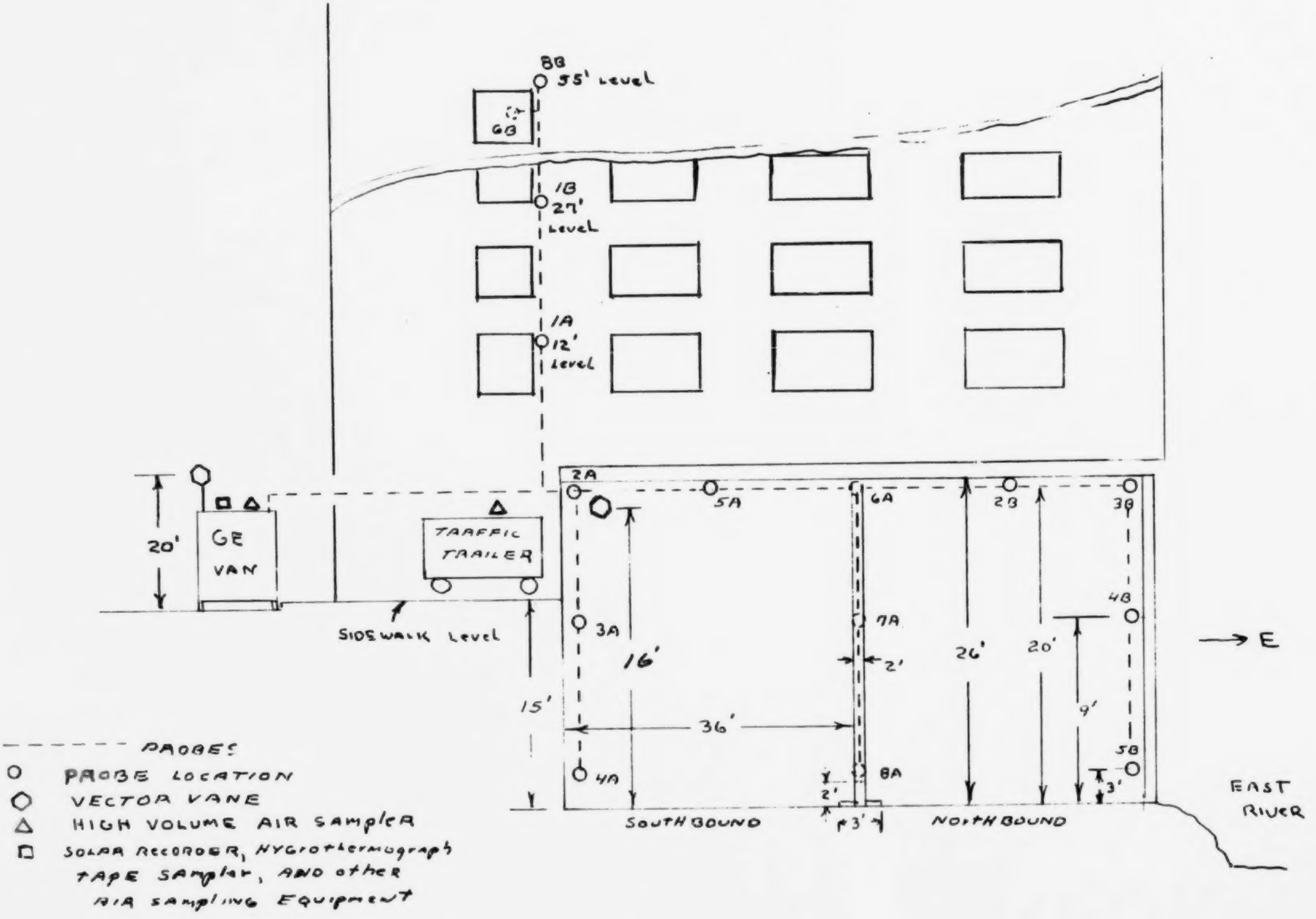
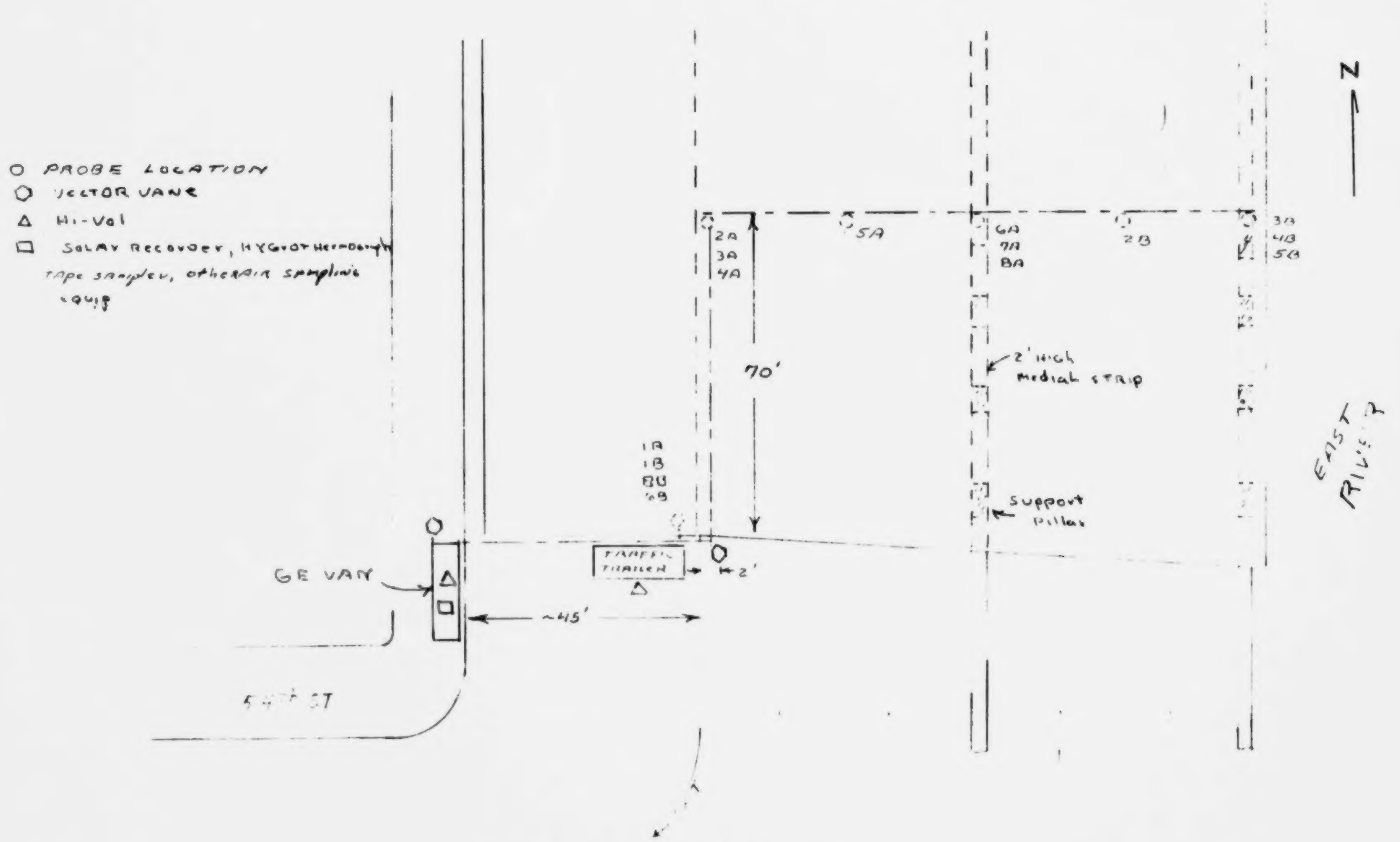
Fig. 4.2-1 Franklin D. Roosevelt Drive at Sutton Place


8B
55' Level
6B
1B
27' Level
1A
12' Level
2A
5A
6A
2B
3B
GE VAN
20'
TRAFFIC TRAILER
SIDEWALK Level
3A
16'
15'
36'
7A
2'
26'
20'
4B
9'
5B
3'
4A
8A
2'
3'
SOUTHBOUND
NORTHBOUND
→ E
EAST RIVER
------ PROBES
○ PROBE LOCATION
⬡ VECTOR VANE
△ HIGH VOLUME AIR SAMPLER
□ SOLAR RECORDER, HYGROTHERMOGRAPH TAPE SAMPLER, AND OTHER AIR SAMPLING EQUIPMENT

Cantilever Covered Roadway - Open At One Side

Figure 4.2-2 Franklin D. Roosevelt Drive @ Sutton Place - Elevation View



○ PROBE LOCATION
⬡ VECTOR VANE
△ Hi-Vol
□ SOLAR RECORDER, HYGROTHERMOGRAPH, TAPE SAMPLER, OTHER AIR SAMPLING EQUIP
N
EAST RIVER
2A
3A
4A
5A
6A
7A
8A
2B
3B
4B
5B
1A
1B
8B
6B
70'
2' HIGH MEDIAL STRIP
SUPPORT PILLAR
TRAFFIC TRAILER
2'
~45'
GE VAN
54TH ST

Cantilever Covered Roadway - Open At One Side

Figure 4.2-3 Franklin D. Roosevelt Drive @ Sutton Place - Plan View

Two weather vanes were installed at this site to measure meteorological conditions. One sensor (designated vane 2 on all figures and tables) was installed on a mast about 7' above the roof of the instrumentation van which was parked at curbside on Sutton Place. The other vane (vane 1) was mounted on a cantilevered support fastened to the fence enclosing the F.D.R. Drive and extending over the outer southbound lane of traffic. This sensor was 16' above the level of F.D.R. Drive. Although it would have been desirable to have this sensor either on the medial barrier or inside the tunnel itself, these locations were impossible due to mounting problems and danger of traffic damage to the sensor or its supports.

One Hi Volume Air Sampler and one Tape Sampler were located on the roof of both the GE Air Pollution Trailer and the New York State Traffic Trailer.

Other instruments used for monitoring the general air quality adjacent to the trailer were as follows:

1. Hydrocarbon analyzer (checking average concentrations of all probes)
2. Anderson Impactors & Membrane Samplers (top of trailer)
3. Solar Recorder - (top of trailer)
4. Nephelometer (particle counter)
5. Climate Particle Counter
6. Hygrothermograph (top of trailer)

4.2.1.3 Meteorological data was obtained at Sutton Place between December 3 and December 10, and those observations taken between December 18 and December 22. This data is documented in Appendix C. During the intervening period, December 11 through 17, both Vector Vane systems were out of service due to storm damage and the unavailability of replacement parts.

The first monitoring period was characterized by very stable meteorological conditions. Winds over the F.D.R Drive blew consistently from a direction of 70° to 80° relative to the roadway. Sigma values were also quite low. The December 18 through 22 period was, in contrast, very turbulent. This can be seen by comparing sigma azimuth and sigma elevation readings for the two periods as shown in Tables C-3, C-6, C-13 and C-16. These tables show the turbulence parameters measured at both vanes to be two to three times higher during the latter period. No significant effect of this increased turbulence can be found on the carbon monoxide averages for those particular days.

There is, however, a dramatic change in concentration levels corresponding to a change in wind azimuth. Wind asimuth, as recorded over the road was quite constant through most of the monitoring period. Winds blew across the road from the river except for two periods: December 18 and 19, 1900 - 0400 hours; and December 21, 0300 to 2400 hours. Unfortunately, December 21 was a Sunday and a considerable amount of CO data is missing. Also, being a portion of a weekend, the hourly concentration means are calculated on a small sample. Comparisons with available mean data show a large reduction in CO levels under the westerly wind regime.

This can be seen by examining the data recorded for probe 2A in Appendix A. During the afternoon and evening of the 21st, CO levels recorded were only about one quarter of the mean values and were, during some hours such as 1800, only one-ninth those recorded at the same hour on a previous Sunday (6 PPM on December 21 vs. 56 PPM on December 7). Since both sigma azimuth and sigma elevation show a large increase on December 21 as compared to December 7, one might conclude that this increased turbulence was the cause of the decreased concentration. However, looking at wind and CO information for December 22, a day with turbulence almost as great as the 21st and certainly higher than average but with a wind from the easterly quadrants, it can be seen that the CO levels are higher than average. The CO levels on this Monday are also generally higher than those for the same hours on previous Mondays with lower turbulence. Thus, it appears that wind direction has a stronger influence on CO levels inside the partially closed tunnel than turbulence.

Figure 4.2-4 shows CO concentration plotted as a function of distance across the road for the one remaining day with a west wind which is December 18. The hours plotted are 1000 and 1100 and the curve stops at mid-road due to missing CO data on the "B" probe side. Curves derived from the mean values are also plotted for comparison. Even though the data is not complete, comparison of the curves reveals the magnitude of the effect of the west wind in lowering pollution levels in the area of the probe plane. The December 18 curve also illustrates another important effect of the westerly wind: that of shifting the maximum concentration away from the wall.

Wind directions recorded by the vane on the instrumentation van differ somewhat from those recorded over the road, A histogram of wind azimuth as recorded by this vane is displayed in Appendix C on Fig. C-11. Due to the restriction that tall buildings impose on the air flow, the air motion was almost always from the north and parallel to Sutton Place.[1] The wind also blew from the opposite direction of a few occasions, making the distribution bimodal. This is a characteristic distribution of any location in which the wind is restricted by walls of buildings or a roadway cut. The fact that the wind blew from slightly east of south instead of being restricted to exactly 180° from the prevailing direction was due to the absence of buildings to the southeast of this sensor.

No diurnal pattern is evident in the averages of the sigma azimuth or sigma elevation wind functions for the sensor over the F.D.R. Drive. (See Appendix C, Figs. C-2 and C-4). Sigma azimuth and elevation were, on the average, higher at the trailer than over the road. This is explained by the close proximity of the road vane to large walls which restricted the free passage and size of eddies.

The majority of elevation readings from the trailer vane centered close to zero. Eighty-five percent of all readings fell between -10 and

---

[1] "North" and "South" directions are used for convenience, realizing that Sutton Place does not run true north and south. All calculations were made and data is presented such that a wind blowing parallel to Sutton Place from Uptown to Downtown is defined as a 0^o wind or a "north wind." The true compass direction of this wind would be about 330^o. Similar conventions are used for subsequent sites.

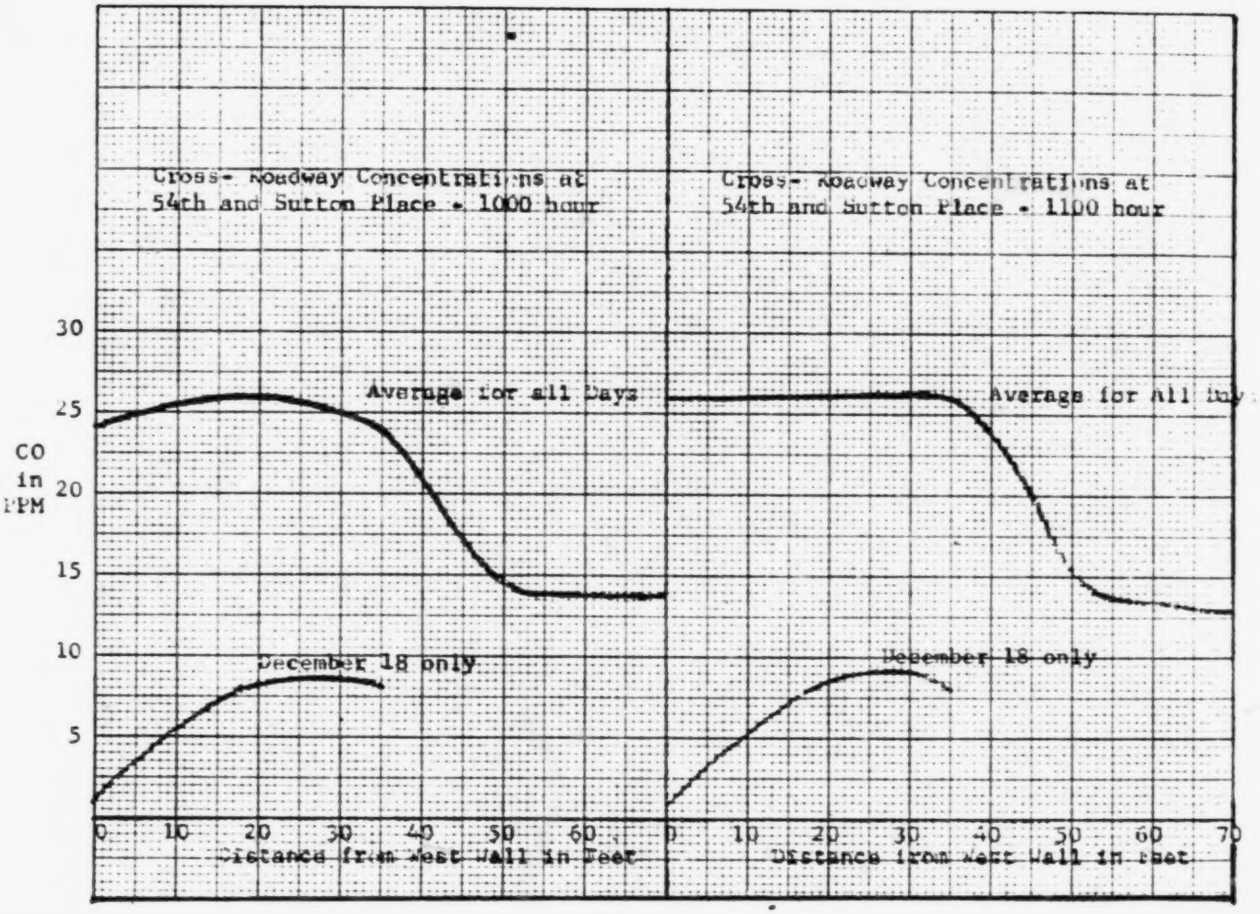


Figure 4.2-4 Carbon Monoxide vs Distance from West Wall

Franklin D. Roosevelt Drive at Sutton Place

+10 degrees. This is as expected, since the sensor was located some distance from obstacles. The remaining 15% of the readings were negative and were probably caused, at least in a large part, by the unbalancing effects of precipitation on the sensor surfaces. The vane over the road, being located beside a retaining wall, would be expected to show the effect of air either ascending or descending the wall face. The elevation angle measured by this sensor did, in fact, show a dependence upon azimuth angle. When the prevailing wind was from the west, the elevation angle was negative indicating air descending over the wall from street level to the level of the F.D.R. Drive. When the wind was from one of the easterly quadrants, the elevation angle was positive, indicating air ascending the wall. Because there was such a preponderance of days with winds from easterly quadrants, and thus rising air, the distribution seen in Figure C-3 is shifted toward positive angles so that it centers about +10°.

The mean wind speed curve for vane 1 presented in Fig. C-5 does show a diurnal pattern. The minimum occurs between three and four in the morning and a broad maximum is in evidence during the afternoon and evening hours. The highest one hour average wind recorded by this vane was 13.5 mph on December 11 between 2400 and 0100 hours. Mean wind speeds recorded at the trailer were generally lower than those recorded over the road. A possible explanation for this is that the means calculated for the trailer vane were based on fewer points than the means for the road vane. The highest one hour average speed recorded by this vane was 15.7 mph between 0100 and 0200 on December 11. The relatively high winds recorded on this date and the subsequent failure of the vane systems coupled with the small number of sample points produced the abnormally high standard deviations seen during the first five hours of Fig. C-13. The diurnal wind speed variation pattern is not as pronounced for the trailer location, probably because of fewer points and the effect of the high winds of December 11 on the morning means.

4.3.1 Brooklyn Battery Tunnel

4.3.1.1 Site Description

The Brooklyn Battery Tunnel, one of four tunnels connecting the island of Manhattan with New Jersey and the boroughs of Brooklyn and Queens, was the long, blower ventilated test site. The tunnel extends from Lower Manhattan to Brooklyn and consists of two tubes carrying a total of 4 lanes of traffic. The roadway cross section is rectangular even though the tunnel itself is tubular. Adjacent to the inside lane of each tube is a 3' wide walkway. The total width of each road is 25'; each lane being 12.5' wide. The height of the tube is ~ 13'. In order to ventilate the tunnel, three ventilation towers were built. One such tower is located in Brooklyn and sits directly above the tunnel supplying clean air to each tube at various points along the roadway. Fresh air enters from both sides of the roadway (~ 2' from roadway) and exhaust vents are located in the roof directly above the center of each lane. The ventilation to the tunnel is manually controlled depending on CO concentrations continuously monitored within. Figure 4.3-1 shows the test locations on the Brooklyn side.

Approximately 51,000 vehicles travel through the Brooklyn Battery Tunnel each day at an average speed of 25 mph. Normally two lanes of traffic occur in both tubes. The daily eastbound and westbound traffic volume is essentially equal. The hourly traffic volume each way varies considerably and peaks at rush hours. Eastbound traffic peaks at 2500 vehicles; the westbound peak is 2430. The rush hour peaks are accommodated by three lanes of traffic in the direction of heavy traffic; limiting the opposite traffic to one lane. This results in two way traffic in each tube at selected hours of the day. During these rush hour peaks, Manhattan bound traffic is slow entering the tunnel. This is the result of merging of traffic from 8 toll booths to the 3 lanes of the tunnel. Brooklyn bound traffic at rush hour, however, is not slowed because the 3 lanes of the tunnel are served by 8 toll booths.

4.3.1.2 Instrumentation Arrangement

The GE Air Pollution Trailer was parked above the tunnel adjacent to the ventilation tower on the Brooklyn side. All wiring and tubing for data gathering were fed through the ventilation tower to both tubes of the tunnel. This routing necessitated using all available tubing to connect the probes in one tube to the instrument van. The CO concentrations were monitored in both tunnel directions by moving the tubing back and forth between the probes mounted in the Brooklyn bound and the Manhattan bound tubes. The van and data sensor locations are shown in Figs. 4.3-2 and 4.3-3.

Fourteen probes were used to monitor the CO concentrations in the tunnel. All the probes were 200' from the opening on the Brooklyn side and in a plane perpendicular to the roadways. Three probes were placed on each wall, at 3', 8', and 13' above the roadway. One probe was located

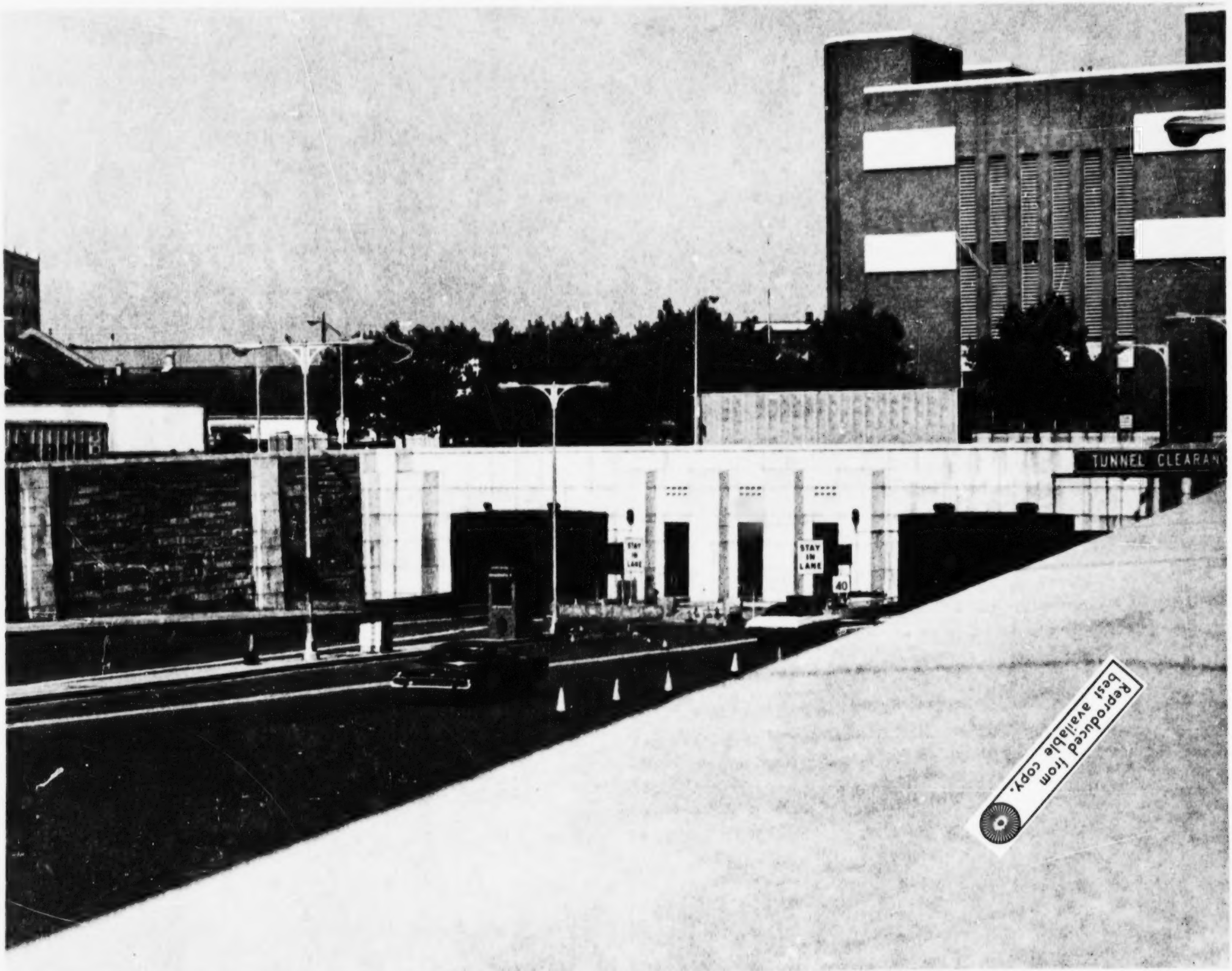

TUNNEL CLEARAN
STAY IN LANE
STAY IN LANE
40

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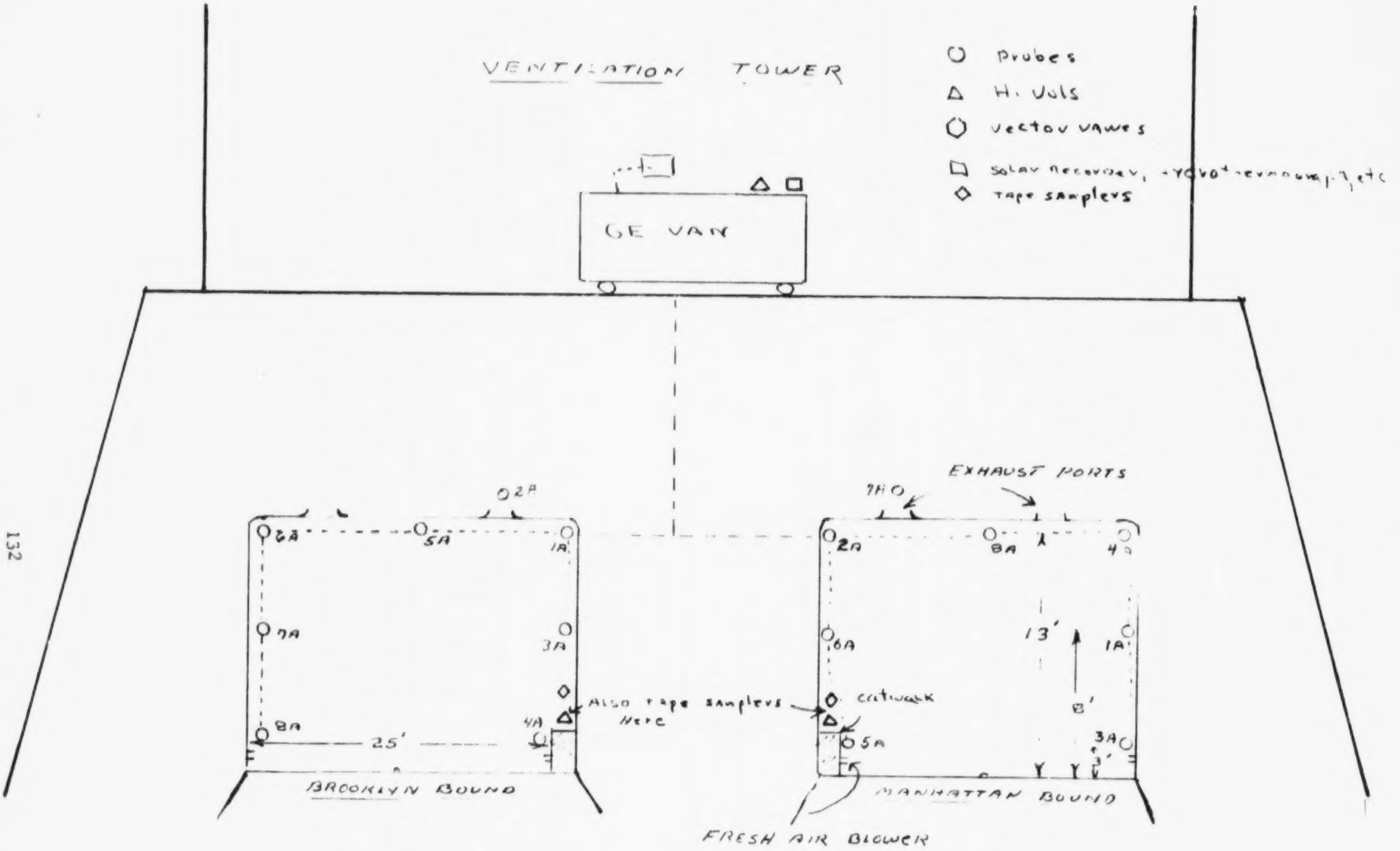
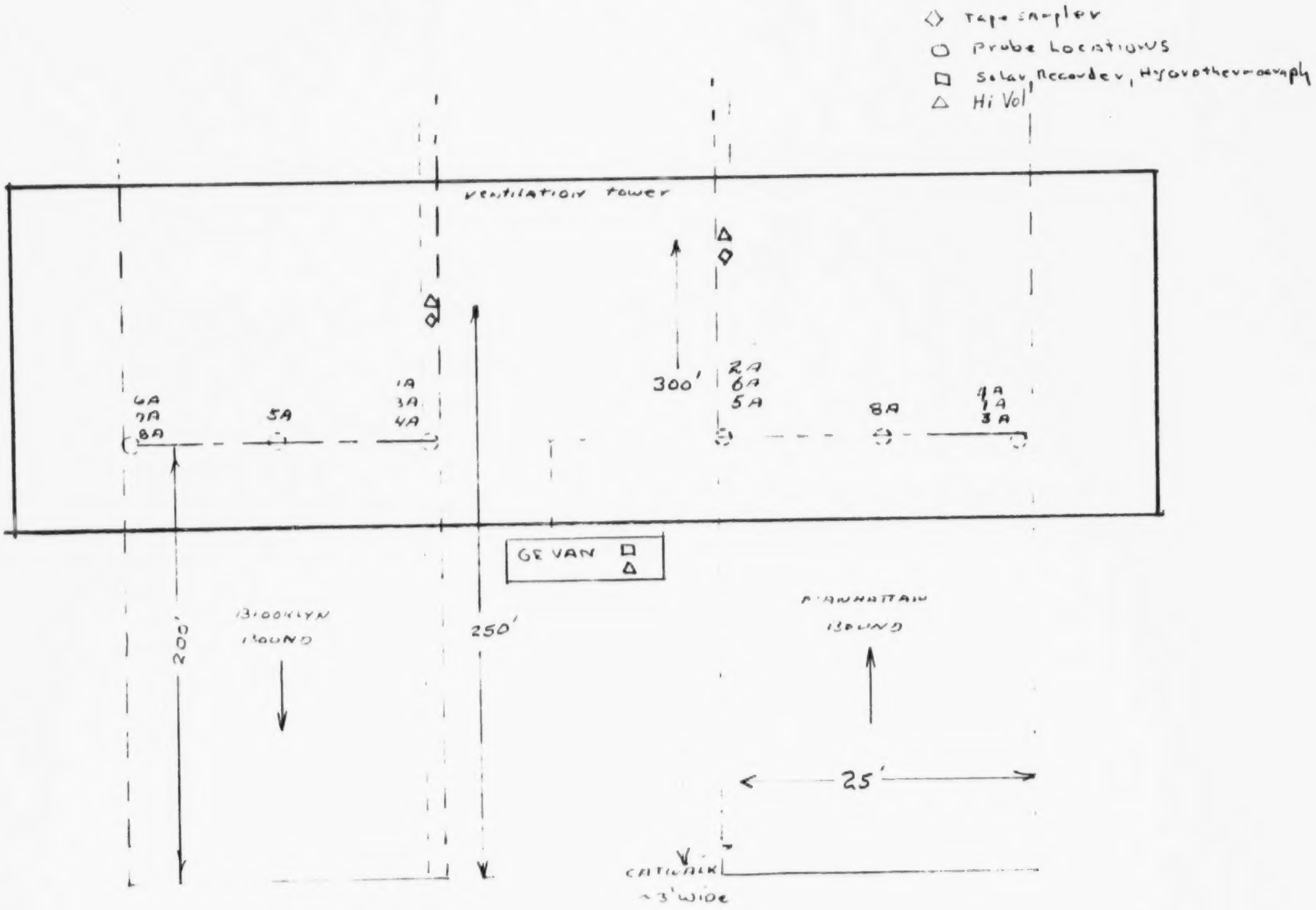
Fig. 4.3-1 Brooklyn Battery Tunnel



VENTILATION TOWER
○ Probes
△ H. Vols
⬡ Vector Vanes
□ Solar Recorder, robot [illegible], etc
◇ Tape samplers
GE VAN
02A
6A
5A
1A
7A
3A
8A
4A
25'
Also tape samplers Here
BROOKLYN BOUND
7HO
EXHAUST PORTS
2A
8A
4A
6A
13'
1A
catwalk
8'
5A
3A
3'
MANHATTAN BOUND
FRESH AIR BLOWER

Long Blower Ventilated, Tunnel

Figure 4.3-2 Brooklyn Battery Tunnel - Elevation View


◇ Tape sampler
○ Probe Locations
□ Solar Recorder, Hygrothermograph
△ Hi Vol
Ventilation tower
6A
7A
8A
5A
1A
3A
4A
2A
6A
5A
300'
8A
4A
1A
3A
GE VAN □ △
200'
Brooklyn Bound
250'
Manhattan Bound
25'
Catwalk ~3' wide

Long Blower Ventilated Tunnel

Figure 4.3-3 Brooklyn Battery Tunnel - Plan View

in the center of each tube, above the two traffic lanes. Two additional probes monitored CO concentration at an exhaust port in each tube at various times during the study.

No weather vanes were used at this site due to the unavailability of a sufficient length of cables to reach the level of the tunnel.

One Hi Vol sampler was located in the tunnel, sampling one tube for several days and then switching to the other tube. The Hi Vol sampling locations were 250' from the exit of the Brooklyn bound tube and 300' from the entrance to Manhattan bound tube. One Anderson Impactor and one Membrane Sampler were also placed at these locations within the respective tubes.

No hydrocarbon measurements were obtained in the Brooklyn Battery tunnel due to the usage of all available tubing for CO data gathering.

4.3.1.3 Meteorological Conditions

No wind data was taken at this site due to an insufficient amount of cable to reach the chosen monitoring position in the tunnel. Personal inspection of the probe plane area resulted in the only estimations of wind speed in the tunnel.

Wind speed was estimated to exceed 20 mph in the Brooklyn bound tube during one-way traffic flow. Air movement was in the direction of traffic motion, that is, toward the Brooklyn exit. Air movement in the Manhattan bound tube was estimated at less than 10 mph during periods of two-way traffic flow. No observation was available during periods of one way Manhattan-bound traffic flow.

4.4.1 Brooklyn Queens Expressway at Hicks Street

4.4.1.1 Site Description

The shallow cut site for this study was chosen along the Brooklyn Queens Expressway along Hicks Street between Kane and DeGraw Streets. At this point, the expressway runs in a North/South direction. The site is a few blocks north of the traffic exchange with the Brooklyn Battery Tunnel. Here in Brooklyn, the elevation of the expressway is 21' below the adjacent roadway levels. The site was an excellent example of shallow cut formation. Two service roads ran parallel to the roadway at this point. A total of six (6) traffic lanes flowed within the shallow cut. Fig. 4.4-1 shows the configuration of the test location, looking north.

Approximately 107,000 vehicles travel daily on the Brooklyn Queens Expressway at Hicks Street. Average traffic speed is 38 mph. The total traffic for each direction is roughly equal (~53,000 each) however, the average peak hourly traffic northbound is 3,430 vehicles while the southbound peak is only 2,980 vehicles.

The elementary school facing the expressway was an ideal place to check indoor CO pollution levels resulting from heavy traffic on the expressway and local traffic on the service road. School representatives were very eager to assist because of their concern for the children studying within the school.

4.4.1.2 Instrumentation Arrangement

The GE Air Pollution Van was parked along Hicks Street directly in front of the Sacred Heart Elementary School which faces the expressway. The locations of the trailer and the data sensors are shown on Figs. 4.4-2 and 4.4-3.

All 16 probes were installed to monitor the CO concentrations. Eleven of these were positioned in a plane perpendicular to the roadway. Three (3) vertical probes were placed down each wall and three down the center to the medial strip. One probe was centrally located, 21 ft. above each direction of traffic. The vertical probes were positioned 3', 14', and 21' from the roadway. Another probe was located 20' above Hicks Street, and monitored the CO emission above the service road. Two CO probes were placed inside the school at 15' and 35' respectively. Two other probes were located outside the school at the same levels. These four probes provided data on the indoor-outdoor CO relationship.

Two vector vane systems were used to monitor wind conditions at this site. One vector vane was placed on the medial strip 14' off the roadway and approximately 15' north of the plane of the probes. Another vane was positioned 18' above Hicks Street on a pole at the intersection of the east wall plane and the plane of the probing. A Hi Vol sampler, solar recorder, and a hygrothermograph were located on the roof of the GE trailer. One tape sample was placed inside the school on the 1st floor. Hydrocarbon concentrations monitored were average values derived from a summation of all probes.

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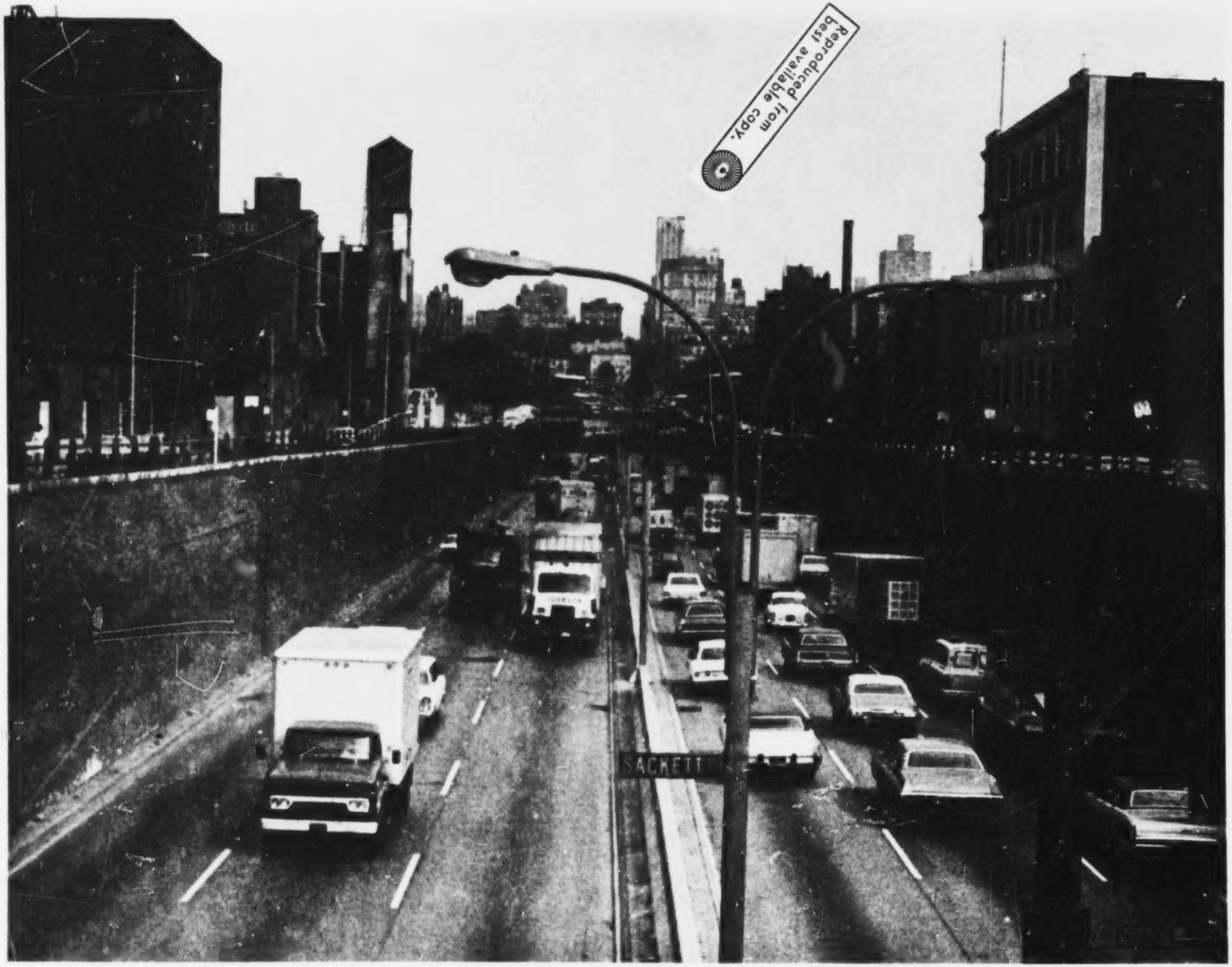
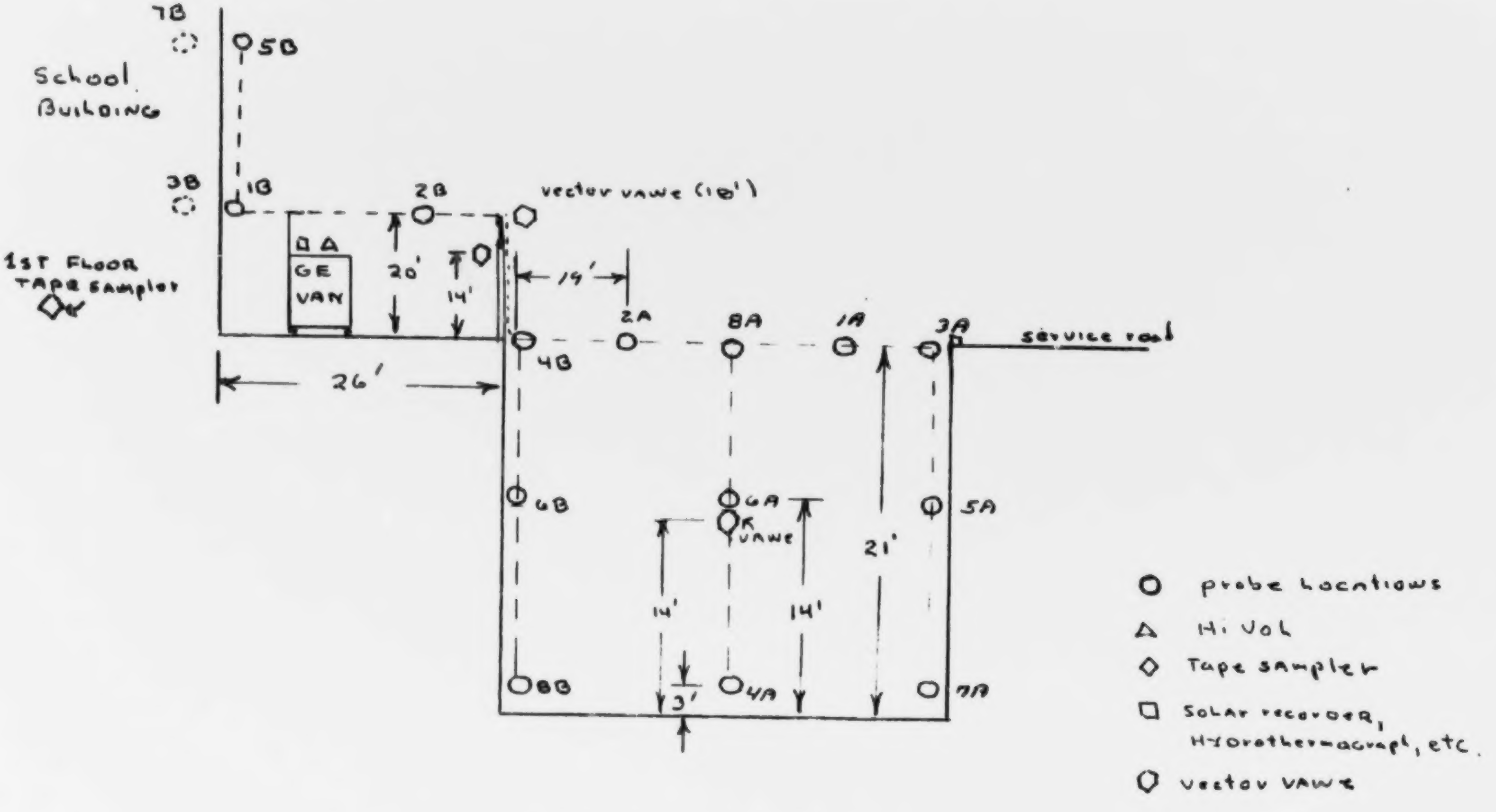
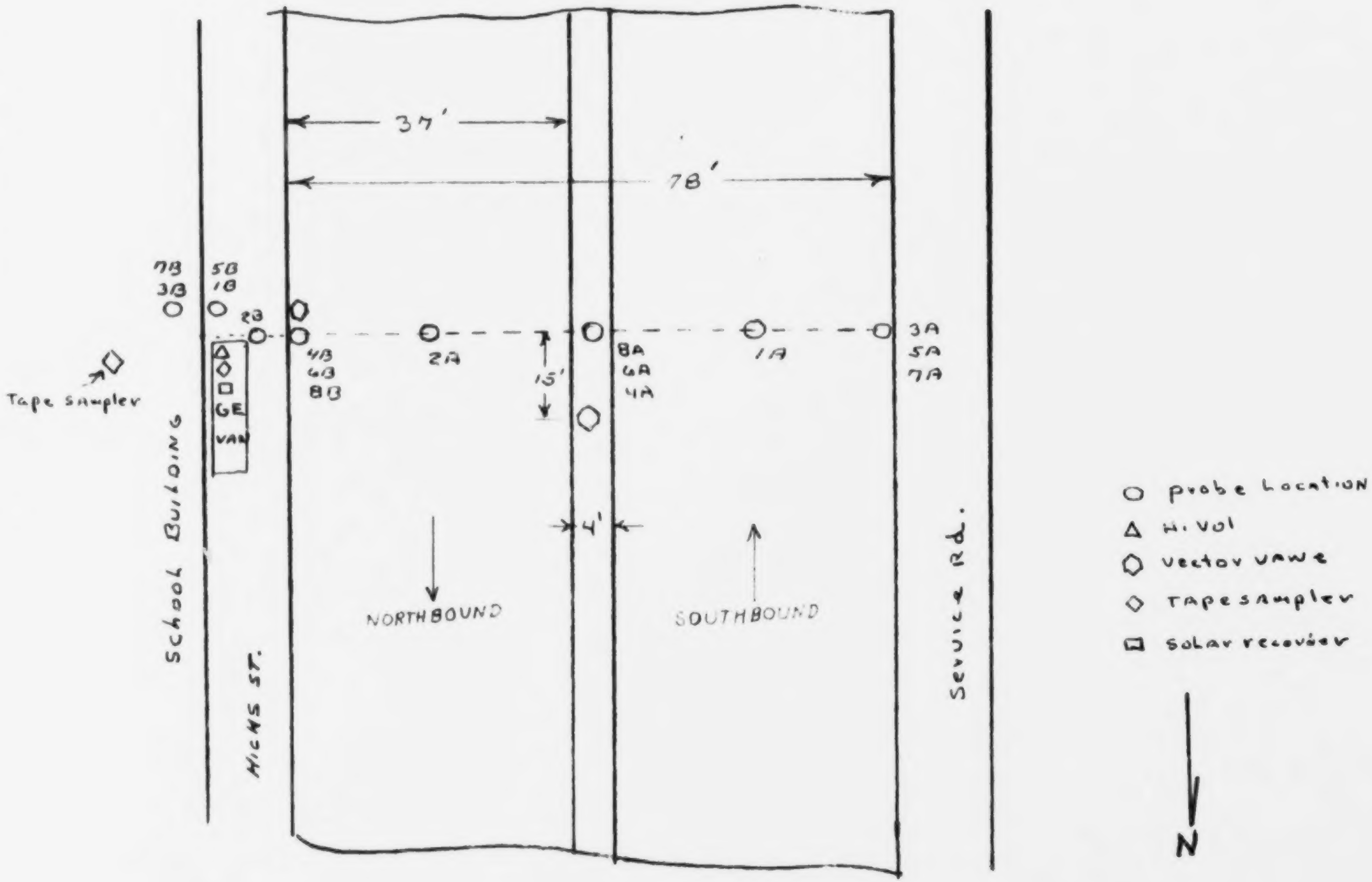


Fig. 4.4-1 Brooklyn Queens Expressway at Hicks Street


7B
5B
School Building
3B
1B
2B
vector vane (10')
1st Floor Tape Sampler
GE VAN
20'
14'
19'
26'
2A
8A
1A
3A
service road
4B
6B
6A
K vane
5A
21'
14'
14'
3'
8B
4A
7A
probe locations
Hi Vol
Tape sampler
Solar recorder, Hygrothermograph, etc.
vector vane

Shallow Cut - Looking South

Figure 4.4-2 Brooklyn Queens Expressway at Hicks Street - Elevation View


37'
78'
7B
3B
5B
1B
2B
4B
6B
8B
2A
15'
8A
6A
4A
1A
3A
5A
7A
Tape sampler
GE
VAN
School Building
Hicks St.
4'
NORTHBOUND
SOUTHBOUND
Service Rd.
Probe Location
Hi Vol
Vector Vane
Tapesampler
Solar recorder
N

Shallow Cut

Figure 4.4-3 Brooklyn Queens Expressway at Hicks Street - Plan View

4.4.1.3 Meteorological Conditions

The wind sensors were installed January 16, 1970 but usable data exists only for the period January 20 to February 5, due to vandalism of sensors and accumulations of road salt on sensors in connectors. Vane 2 was severely and repeatedly affected by salt spray from passing vehicles on the nearby service road, rendering all channels except azimuth and sigma azimuth inoperative for the duration of monitoring. The azimuth angle as recorded by Vane 2 shows that, for the main portion of the monitoring period, the air flow was parallel to the Brooklyn Queens Expressway towards Queens (see Fig C-25 in Appendix). Air sometimes moved across the top of the cut from east to west as can be seen in the same figure but almost never flowed in the opposite direction. This cross-highway wind is in reality, the lower branch of an eddy formed over the Brooklyn Queens Express by the influence of nearby buildings. Figure 4.4-4 illustrates this eddy which was observed during westerly and northwesterly wind flow only. This figure depicts a smoke plume from a nearby factory which made the eddy visible several times during westerly flow. A plot of wind direction vs. time at the Central Park National Weather Service observation point, as well as the direction recorded by Vane 2 just above the cut at Hicks St., is presented in Fig. 4.4-5. The six day period chosen to illustrate the eddy effect exhibits several changes in wind direction. On January 24, as the general wind flow over the city trends towards north through west, the wind recorded above the cut trends toward north but through the easterly directions. This occurs again on January 26. General southerly winds in the area also produce southerly winds over the cut and elimination of the eddy (January 25 and January 28). This same elimination of the eddy would be expected of northerly winds over this N-S street but northerly winds were too infrequent to illustrate this point.

The eddy, as can be seen in Figure 4.4-4 may be expected to drag clearner air from aloft down the face of the school building and across the expressway. This fact may be demonstrated by comparing measured CO pollution levels on days when the eddy was present with levels recorded on days when the wind flow was parallel to the road. Figure 4.4-6 is a plot of carbon monoxide concentration vs. time of day for two days, January 26 and 27. An examination fo the curves discloses that the levels on January 26 were trending downward during the day and the levels on January 27 were trending upward. Referring to Figure 4.4-5, it can be seen that the eddy (showing as an easterly component on the Brooklyn Queens Expressway data) makes its appearance at about noon on the 26th and vanishes at about the same time on the 27th. The carbon monoxide concentrations rise and fall in concert with these changes in direction, being generally high until about noon on January 26, then falling to comparatively low levels over the ensuing 24 hours. Pollutant levels become elevated again on afternoon of January 27. It is interesting to note the magnitude of the eddy effect on pollutant levels on these two days. (It should be noted that traffic volumes were approximately equal on the two weekdays.) During the early morning hours, carbon monoxide concentrations were almost 4 times higher during southerly wind regimes than during easterly flow. During the late evening, the CO levels occurring when the flow as parallel to the street were about twice as high as those influenced by the eddy circulation.

The sigma azimuth readings from Vane 2 were markely higher during periods of easterly flow at the vane level. These high values promote

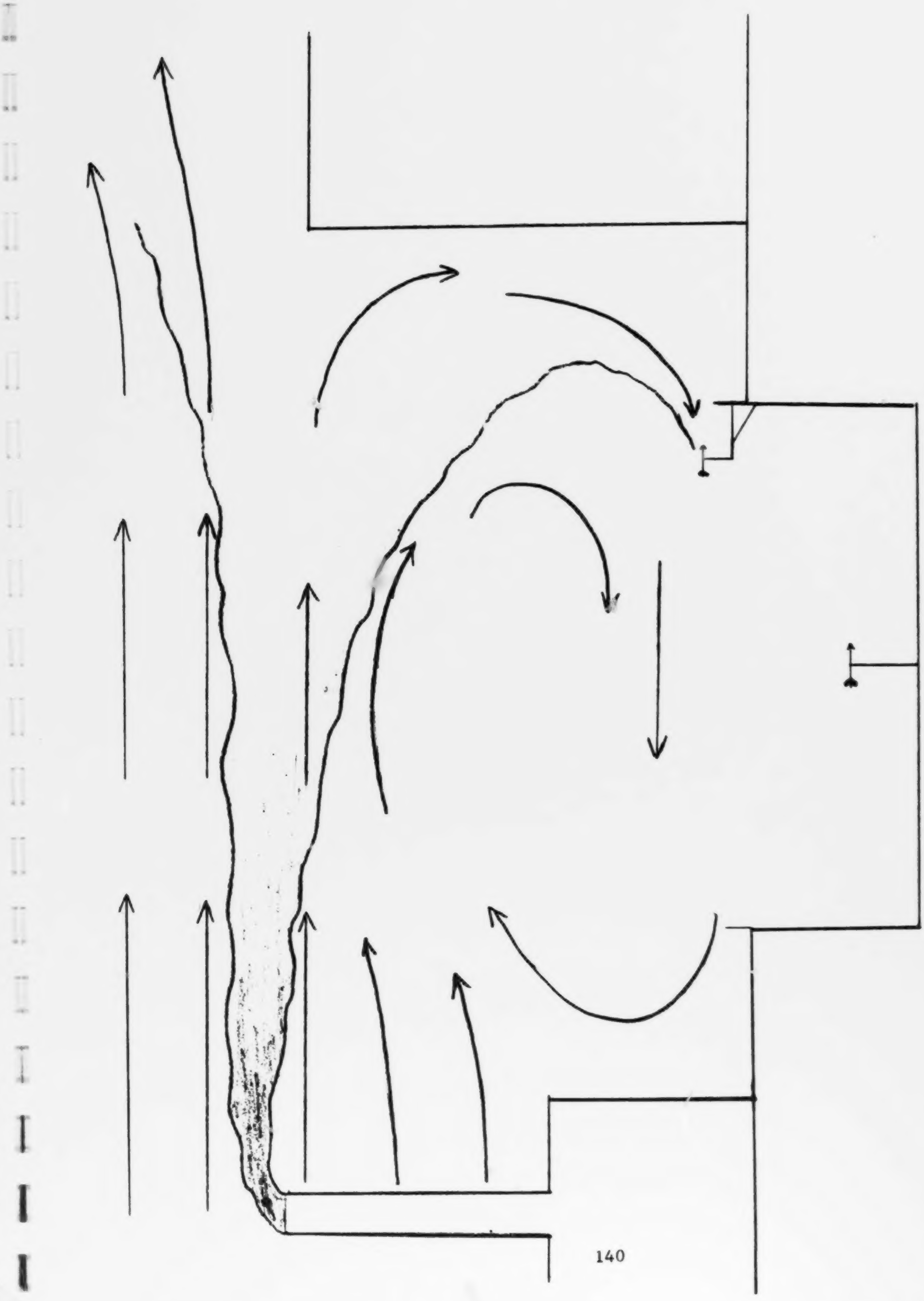


Figure 4.4-4 Illustration of Eddy over the Shallow Cut on the Brooklyn - Queens Expressway at Hicks Street

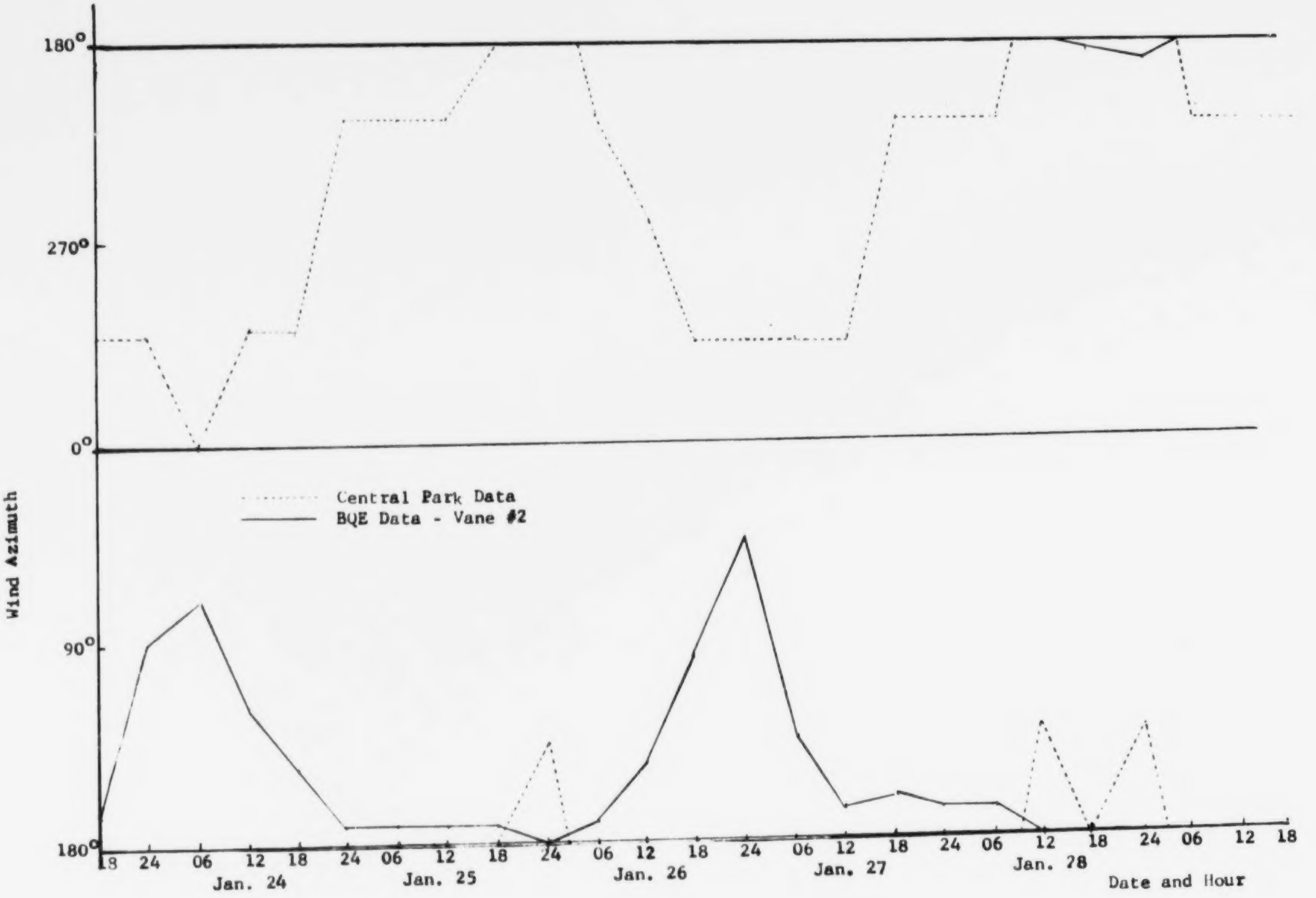


Figure 4.4-5 Comparison of Wind Azimuth Between Central Park Station and Hicks Street Site

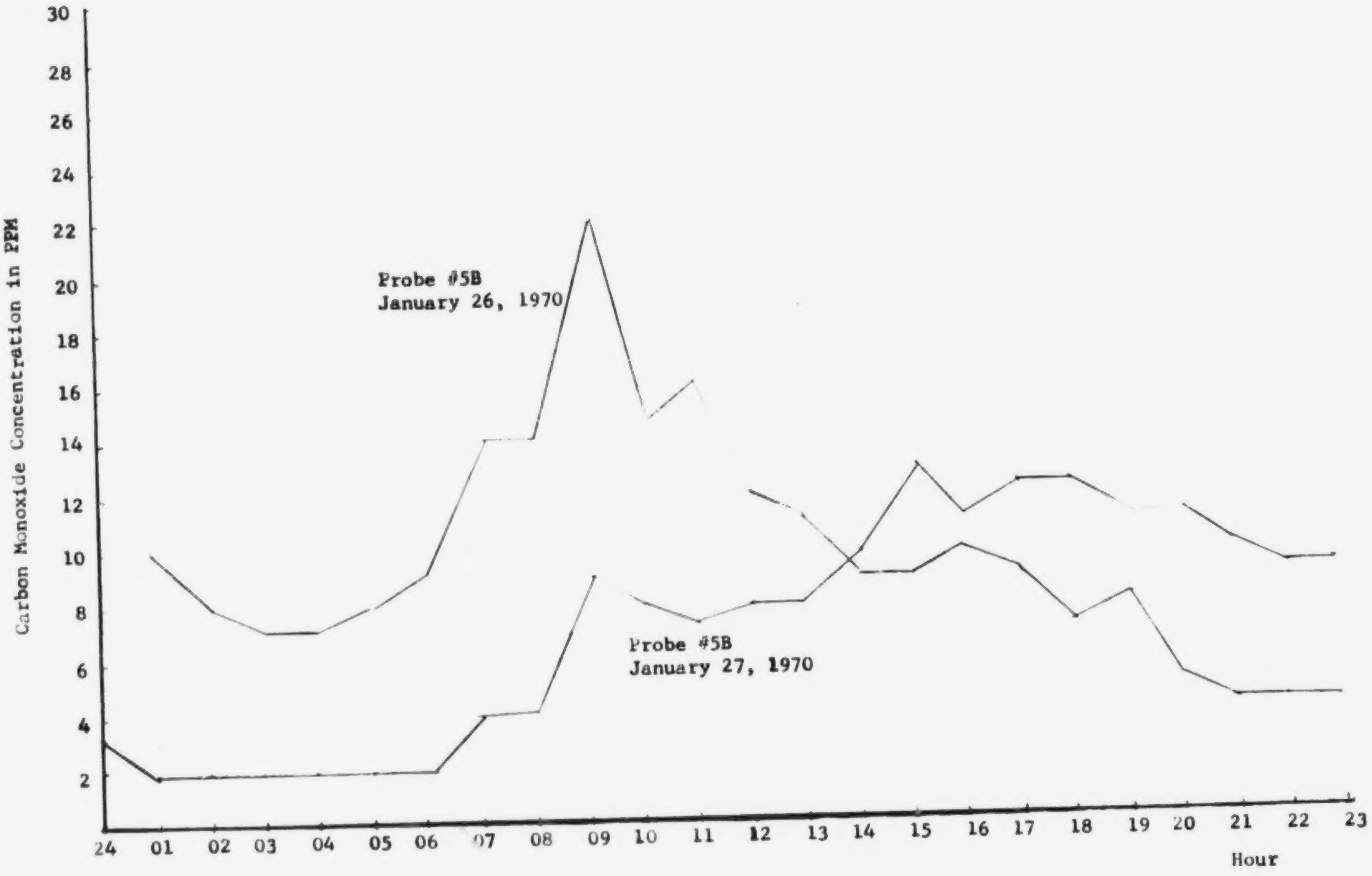


Figure 4.4-6 Carbon Monoxide Levels on Two Days Under Different Wind Regimes

vigorous mixing and diffusion of the CO and would tend to generally lower concentrations at the probe locations. The amount of reduction in concentration on such days as January 26th and 27th, due simply to the increase in turbulence and not to a different air source, cannot be estimated from the present data, since all turbulent days were also eddy days and all non-turbulent days were during periods with winds parallel to the street. Both the increased turbulence and the transport of cleaner air from roof level down into the street lead to decreased concentrations.

An examination of the mean sigma azimuth plot (Figure C-26) discloses very little resemblence to the expected diurnal pattern. The curve is quite flat with only a hint of a minimum in the early morning hours. This is undoubtedly due to the small sample size and considerable missing data. Weather systems were quite active during this period and a larger sample would be needed to obtain a representative diurnal curve.

The azimuth frequency of occurrence chart for Vane 1 (median strip) found in Figure C-21, shows very little remnant of the eddy circulation in the cut itself. The distribution shows two maximums, one near 0^o and the other near 170^o. In other words, the air in the cut almost always moves parallel to the cut. A wind from any northerly quadrant above the cut generally becomes a northerly wind in the cut and a wind from any southerly quadrant becomes southerly. An additional illustration of the restricted flow in the cut may be found by comparing Figure C-23, the plot of the mean u component with Figure C-24, the plot of the mean v component. The wind component parallel to the road (u) is consistently at least twice that of the component across the road (v).

Mean sigma azimuth as recorded on the median is of approximately the same magnitude as that recorded above the cut. The mean values (Figure C-18) again display only slight resemblence to the expected diurnal pattern. A minimum occurs early in the morning, as would be expected; however, another minimum occurs at 6 PM. The maximum occurs at 9 AM. Any effect of traffic generated turbulence on sigma azimuth appears to have been effectively masked by large weather variations and, possibly, the inclusion of weekend data in the means. That large day to day variations were the rule in this function may be seen by examining the standard deviation curve on Figure C-18. The magnitude of the standard deviation is 1/3 that of the mean values for almost all hours.

The wind elevation angle as recorded on the median is presented in Table C-24 and a frequency histogram may be found in Figure C-19. The average angle is very near, but just slightly negative of zero degrees (horizontal). 83% of all readings fell between 0^o and -10^o. Although this negative angle would appear to indicate a slight downdraft condition, the unbalancing effects of precipitation as well as salt and dirt deposits on sensor tail surfaces may have contributed some inaccurate measurements. As access to sensors, after initial installation, was generally restricted by traffic and safety factors, the quantitative effects of deposits could not be determined by removing the sensor and measuring the balance point in a quiet atmosphere. In any case, the angle is so small that the mean vertical velocities are usually only .5 mph. (See Table C-38 and Fig. C-30).

Sigma elevation readings from Vane 1 were among the highest encountered at the nine sites for which wind data is available. However, the mean hourly values (Figure C-20) again exhibit the strange minimum near 6 PM and rising values thereafter that was found in the sigma azimuth curve. The diurnal curve is again more the reflection of frontal passages and storms than turbulence generated by passing vehicles.

The highest wind speed recorded in the cut (hourly average) was 18 mph from the south. This value was recorded on February 2 at 1500. Gusts during that hour reached over 40 mph and the wind system failed shortly thereafter.

4.5.1 Cross Bronx Expressway at Hugh J. Grant Circle

4.5.1.1 Site Description

The short unventilated tunnel situated beneath Hugh J. Grant Circle on the Cross Bronx Expressway was the fourth site visited in the Urban Expressway study. A total of 6 lanes of traffic flow through this tunnel. A wall divides the 3 west bound lanes from the 3 east bound lanes. The tunnel is not ventilated so high pollution levels were expected. The test roadway is once again lower than the surrounding ground level as shown in Figure 4.5-1.

Approximately 86,000 vehicles pass thru the tunnel daily. The eastbound lanes carry 44,000 vehicles at an average speed of 42 mph. 42,000 vehicles travel westbound at 48 mph. The eastbound traffic volume rises during both the morning and evening work hours and peaks at 2860 vehicles about 5 PM. The westbound traffic is relatively constant between 8 AM and 6 PM, with a 2570 vehicle peak near 3 PM.

4.5.1.2 Instrumentation Arrangement

The GE trailer was parked on the north side of the Cross Bronx Expressway at the west end of the tunnel approximately 25' above the surface of the roadway.

A total of 16 CO probes were in the tunnel, as shown in Figures 4.5-2 and 4.5-3. Six probes were placed in each side of the tunnel, 100' from the west end, in a plane perpendicular to the traffic flow. Three of these probes were 3', 9', and 16' off the roadway along the inner walls. Two probes were located along the outer wall at 3' and 16'. One probe was also placed at the 16' height over the geometor center of the roadway in each direction. Another probe was placed in each side of the tunnel at the 16' level along the north wall at a distance of 50' from the west bound exit. One probe was placed adjacent to the west bound opening of both sides of the tunnel at 16'.

One vector vane (vane 2) was installed on the median strip of the Cross Bronx Expressway 14' above the road surface and 32' west of the Grant Circle tunnel. This was approximately in the middle of the open space formed between Grant Circle and the White Plains Road overpass. The other wind sensor (vane 1) was placed, in an inverted position, over the exit of the westbound tunnel. It was 14' above the road surface.

A Hi Vol and a tape sampler were located on the median strip, adjacent to vector vane 2. A Hi Vol sampler, a solar recorder, and the hygrothermograph were located on the roof of the trailer.

4.5.1.3 Meteorological Conditions

Wind monitoring commenced at this site on February 19, and ended on March 6. Again at this site, the amount of data collected was reduced by equipment breakdowns and malfunctions as well as difficulty of access to equipment in the middle of an expressway. All channels on vane 1 (over the tunnel entrance) except for wind speed failed on February 27 and remained inoperative for the duration of monitoring at this site. Azimuth

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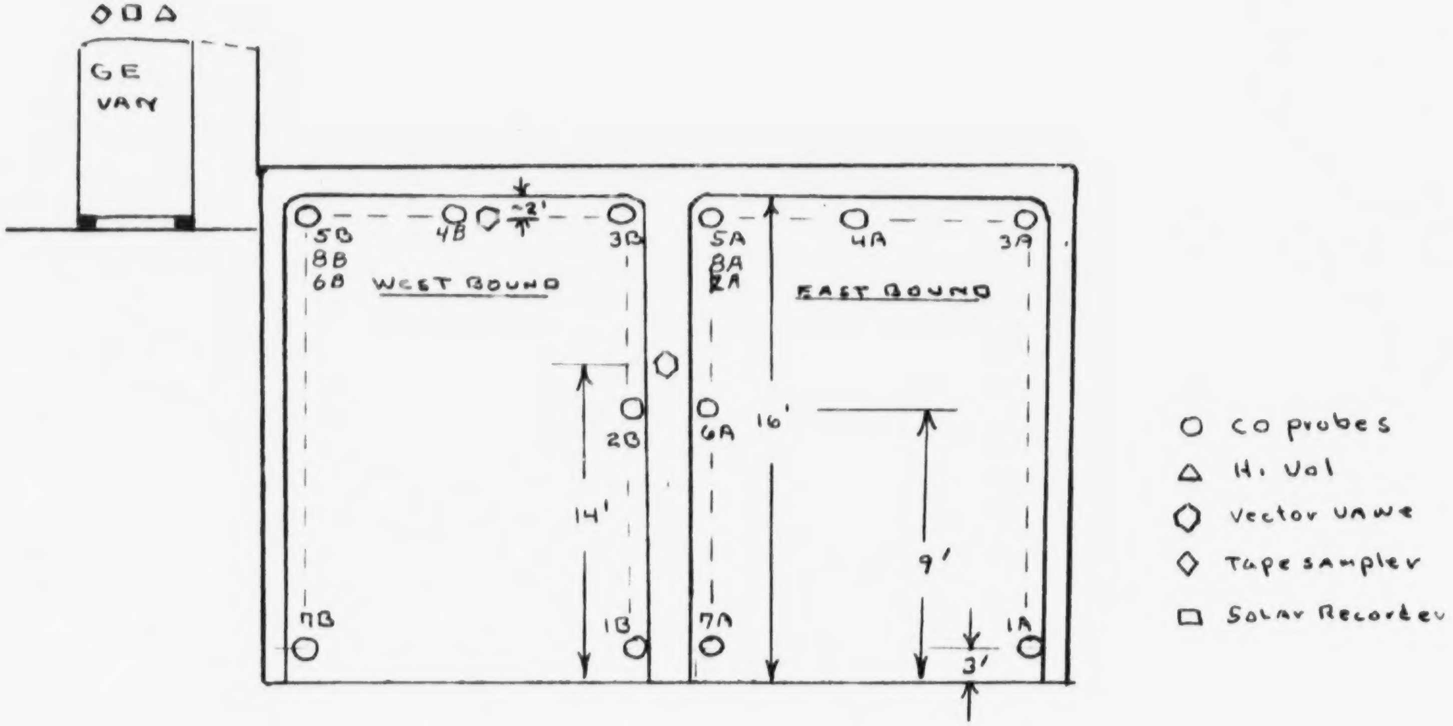
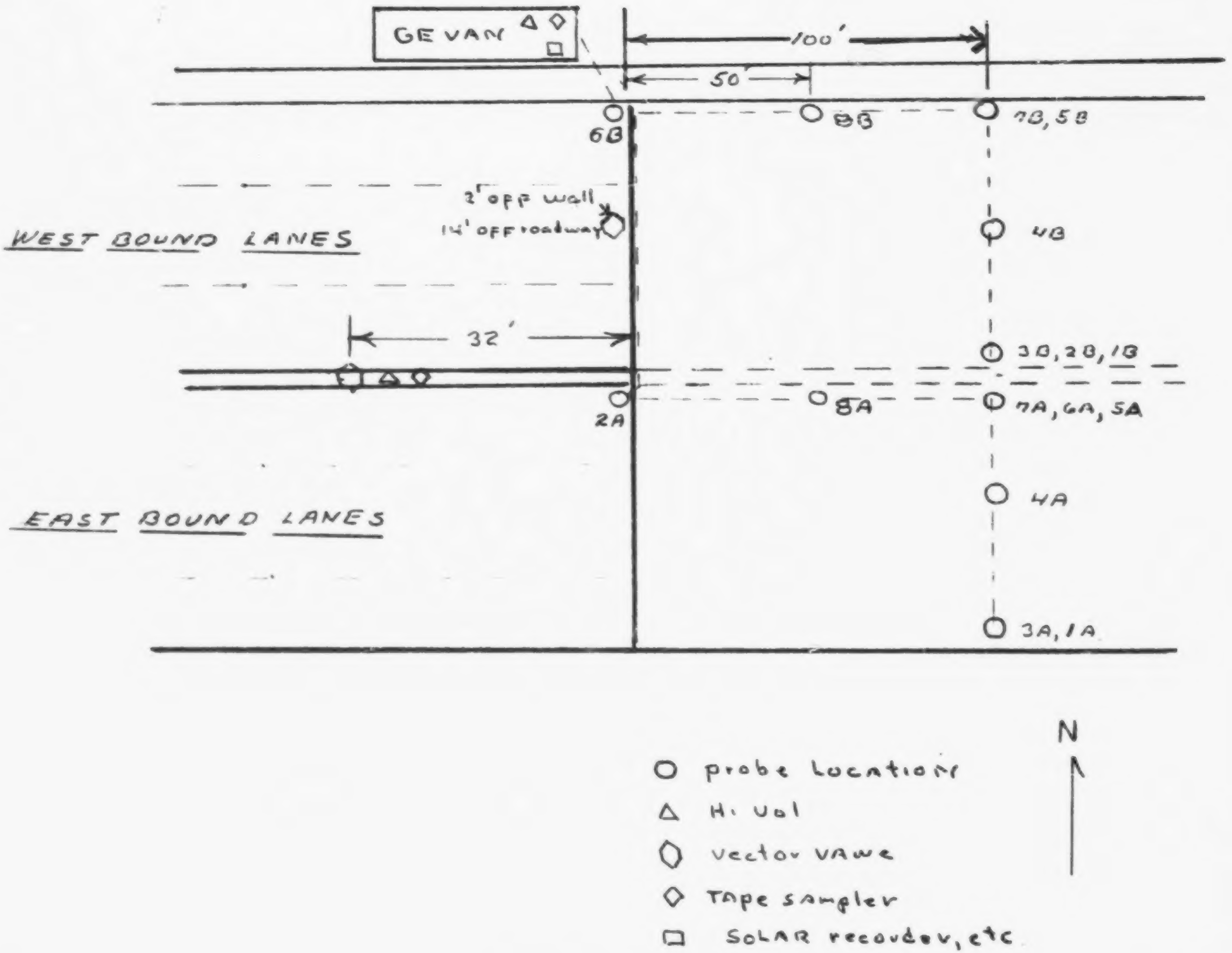
4.5-1 Cross Bronx Expressway at Hugh J. Grant Circle


GE
VAN
5B
8B
6B
4B
~2'
3B
WEST BOUND
2B
14'
7B
1B
5A
8A
2A
4A
3A
EAST BOUND
16'
6A
9'
7A
1A
3'
CO probes
Hi Vol
Vector Vane
Tape sampler
Solar Recorder

Short Unventilated Tunnel

Figure 4.5-2 Cross Bronx Expressway At Hugh J. Grant Circle - Elevation View


GE VAN
100'
50'
6B
8B
7B, 5B
2' off wall
14' off roadway
WEST BOUND LANES
4B
32'
3B, 2B, 1B
2A
8A
7A, 6A, 5A
4A
EAST BOUND LANES
3A, 1A
N
○ probe Location
△ Hi Vol
⬡ Vector Vane
◇ Tape sampler
□ Solar recorder, etc

Short Unventilated Tunnel

Figure 4.5-3 Cross Bronx Expressway at Hugh J. Grant Circle - Plan View

and sigma azimuth functioned fairly well on vane 2, however, elevation and sigma elevation were missing from February 27 through March 6. Virtually no wind speed data was obtained from sensor #2. All wind data and statistics for this site are presented in Figures C-33, through C-47, and Tables C-41 through C-60 in Appendix C.

Wind azimuth as recorded on the medial barrier shows a bimodal distribution as can be observed in the histogram in Figure C-33. This type distribution occurs because the portion of the site in which the vane was located was actually a shallow open cut. The sensor over the westbound tunnel exit indicated that the wind blew from the east during the majority of recorded hours. This is probably due to the traffic in the tunnel inducing a wind in the direction of traffic motion.

The plot of sigma azimuth vs. time as recorded by the median vane showed only slight evidence of a diurnal pattern. Also, the values recorded at this vane are lower than those recorded by the tunnel vane. This is due to several factors. First, the sample period and number were not the same for both sensors and a certain amount of the data is doubtful due to missing and damaged tail surfaces. The effect of missing tail surfaces on the median vane would normally be evident in the elevation data due to the resulting sensor imbalance. Data presented in Tables C-54, C-55 and Figure C-43 does show the highest elevation angle frequency of occurrence to be almost 50° from the horizontal. This is very unexpected since the sensor was not placed near any obstacle. Close examination of the strip chart records disclosed the presence of an electronics malfunction in the elevation channel which masks any difference between good and bad data received from the sensor. For this reason, there is no way to edit the sigma azimuth data to remove incorrect readings.

The elevation channel malfunction naturally affected the input to the elevation sigma computer. This resulted in values far below those recorded at the mouth of the tunnel and also far below what they actually should be. The wind speed channel in this sensor operated for only one day, thus precluding any analysis.

The sensor over the tunnel exit (#1) provided fairly reliable sigma azimuth data over a period slightly in excess of one week. As this sensor was in close proximity to the traffic, the effect of vehicle motion may be seen in the sigma azimuth measurements. Figure 4.5-4 presents diurnal plots of the mean sigma azimuth as recorded at vane 1 and the traffic flow leaving the tunnel. The similarity in shape of the two curves illustrates the effect of moving vehicles on the nearby atmosphere. The absolute minimum and relative minima and maxima of the two curves occurs during the same hour in may instances, such as 0300, 0700, 0800, 1700, 2200 and 2300 hours.

The effect of traffic generated turbulence is not seen as clearly in the sigma elevation channel. Turbulence was so extreme during a large number of hours that the sigma meter constantly read full scale. The lack of sufficient range in the instrument caused the range of average values to be compressed. Although the minimum values still appear in the early morning (see Figure C-36), the values for the remainder of the day are constant, at or near the full scale reading of 22.5°.

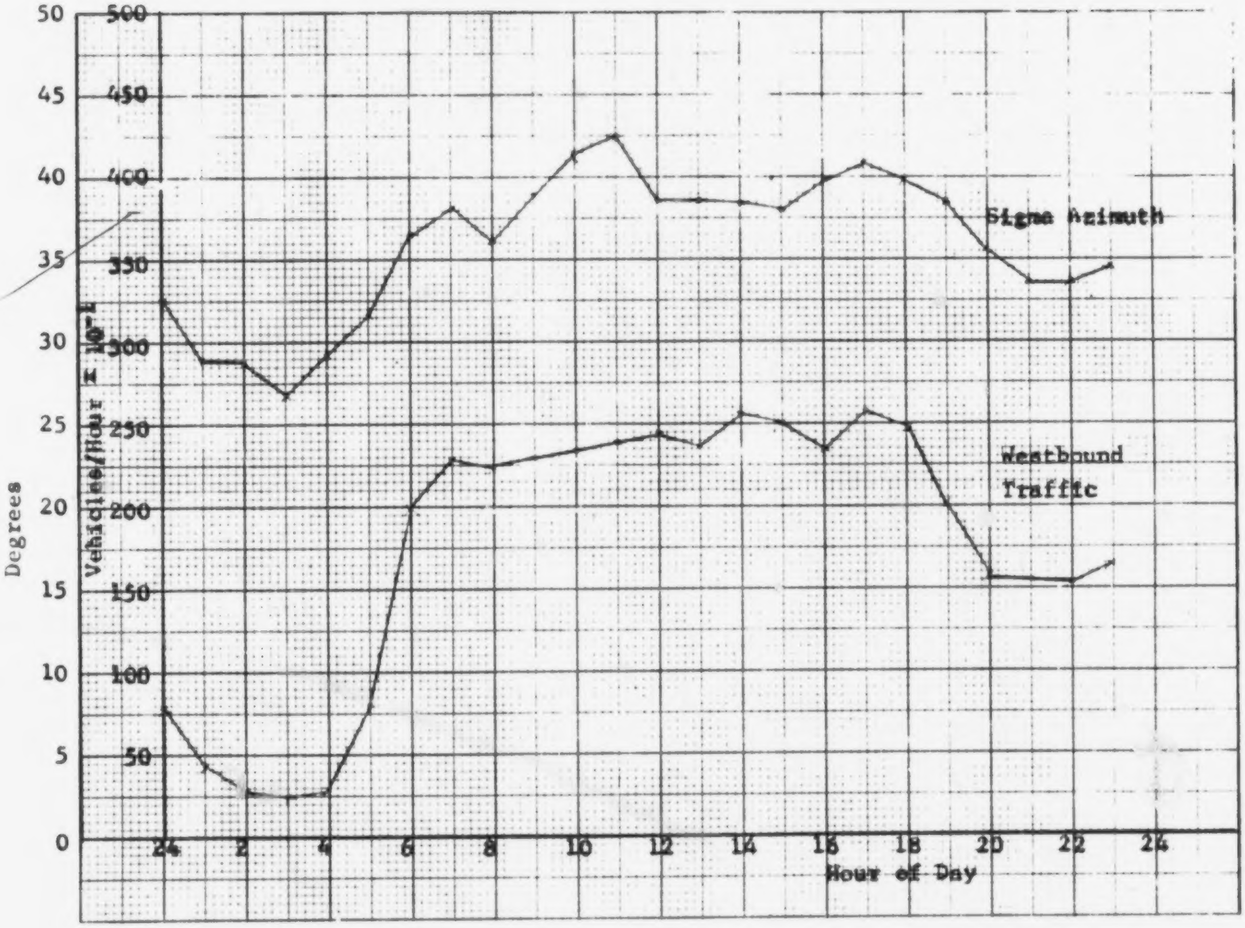


Figure 4.5-4 Comparison of Traffic and Turbulence Curves at Hugh J. Grant Circle

The diurnal variation in the average wind speed curve, as depicted in Figure C-37, is slight with the range between maximum and minimum equal to 1.1 mph. The highest average wind speed recorded at this site was 10 mph as noon on February 23. The wind speed at this sensor never dropped below 2.0 mph even during the early morning hours. This is probably due, at least in part, to the motion of traffic beneath the sensor generating some local air motion even when the lower atmosphere was calm.

4.6.1 Cross Bronx Expressway at Nelson and Jessup Avenues

4.6.1.1 Site Description

The Cross Bronx Expressway between Nelson and Jessup Avenues is a perfect example of a deep cut site. The roadway cuts through solid rock, 55' lower than the north service road where the GE air pollution trailer was located. A total of eight lanes of two way traffic flowed on the expressway beneath the Jessup Avenue Bridge. The bridge is ~210 ft. long and spans the expressway at this point. The one wall running down to the expressway is brick while the other side is solid rock. The brick wall is not perpendicular but is angled toward the roadway. The other side is completely irregular in appearance composed completely of rock and gravel. One lane in the westbound direction is an exit lane while in the eastbound direction, one lane is an entrance lane. There is a slight upward grade when traveling westbound on the expressway. Figure 4.6-1 shows the site, looking westbound.

Approximately 118,000 vehicles use the Cross Bronx Expressway at this point each day. Traffic peaks occur in both directions during both the morning and evening rush hours. The eastbound traffic peaks at 3590 vehicles while the westbound peak reaches 4010 vehicles. 58,000 vehicles travel eastbound at an average speed of 49 mph. The westbound traffic of 60,000 vehicles averages 47 mph.

4.6.1.2 Instrumentation Arrangement

The GE Van was located on the north service road 55' above the surface of the roadway and about 83' west of the Jessup Avenue Bridge. The site and probe configuration are shown in Figures 4.6-2 and 4.6-3.

Sixteen probes were used to monitor the CO concentration in and adjacent to the site. Three sets of probes were positioned from the bridge down to the roadway. One set went down the brick wall along the westbound lanes, one down the middle and the last down the stone wall. Each set contained three probes. These probes were located 3', 26' and 55' above the roadway.

Another probe was located over the westbound lanes, 55' off the roadway. Three additional probes ran down the brick wall (north side) 83' west of the bridge. One probe monitored the CO concentrations at the top of the cut on the north side 45' from the bridge. Two probes sampled ambient air in the trailer

A Membrane sampler, an Anderson Impactor, a tape sampler, Hi Vol Particulate sampler, a Solar recorder, and a hygrothermograph were all located on the trailer roof.

One vector vane was located on the medial strip 45' west of the Jessup Avenue Bridge. The vane was 14' off the roadway.

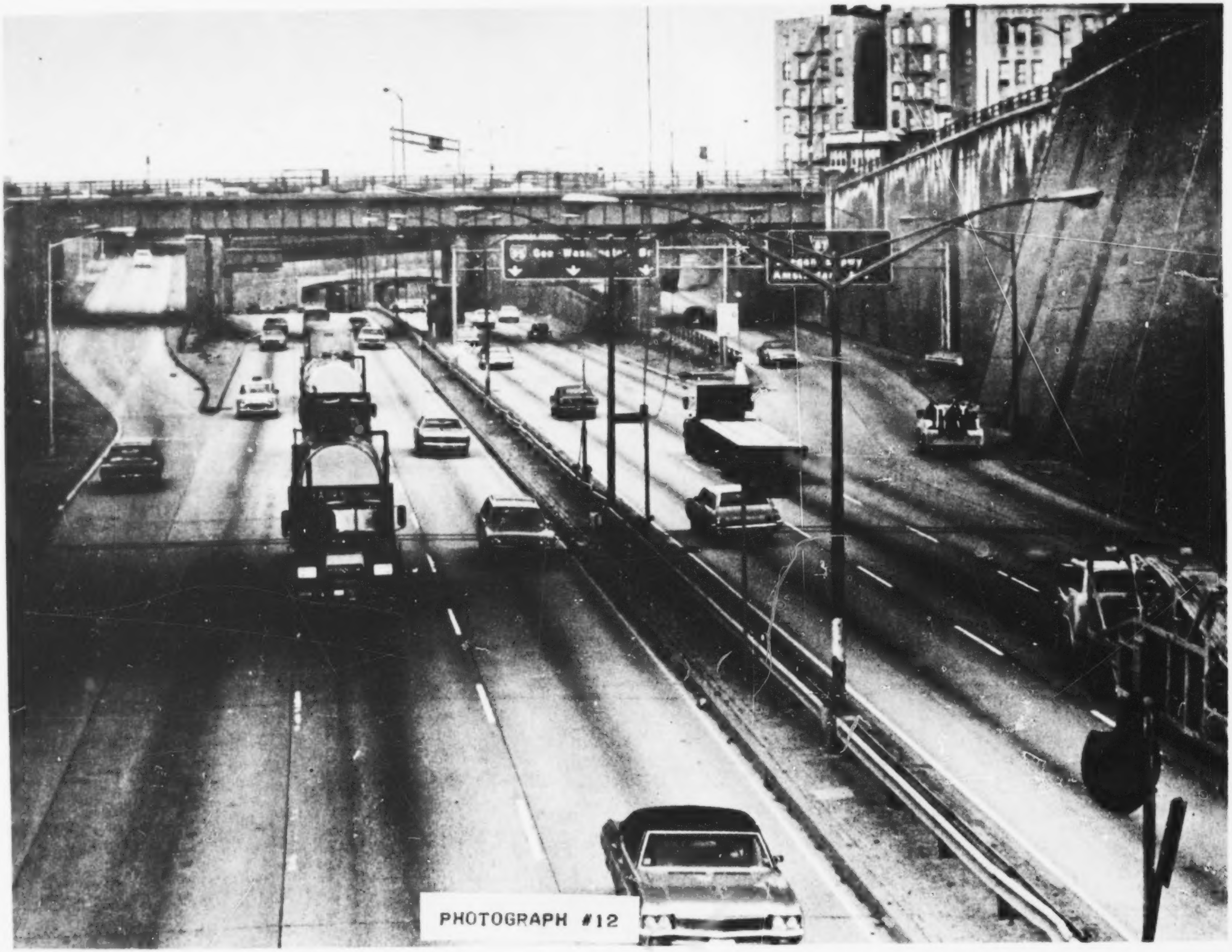

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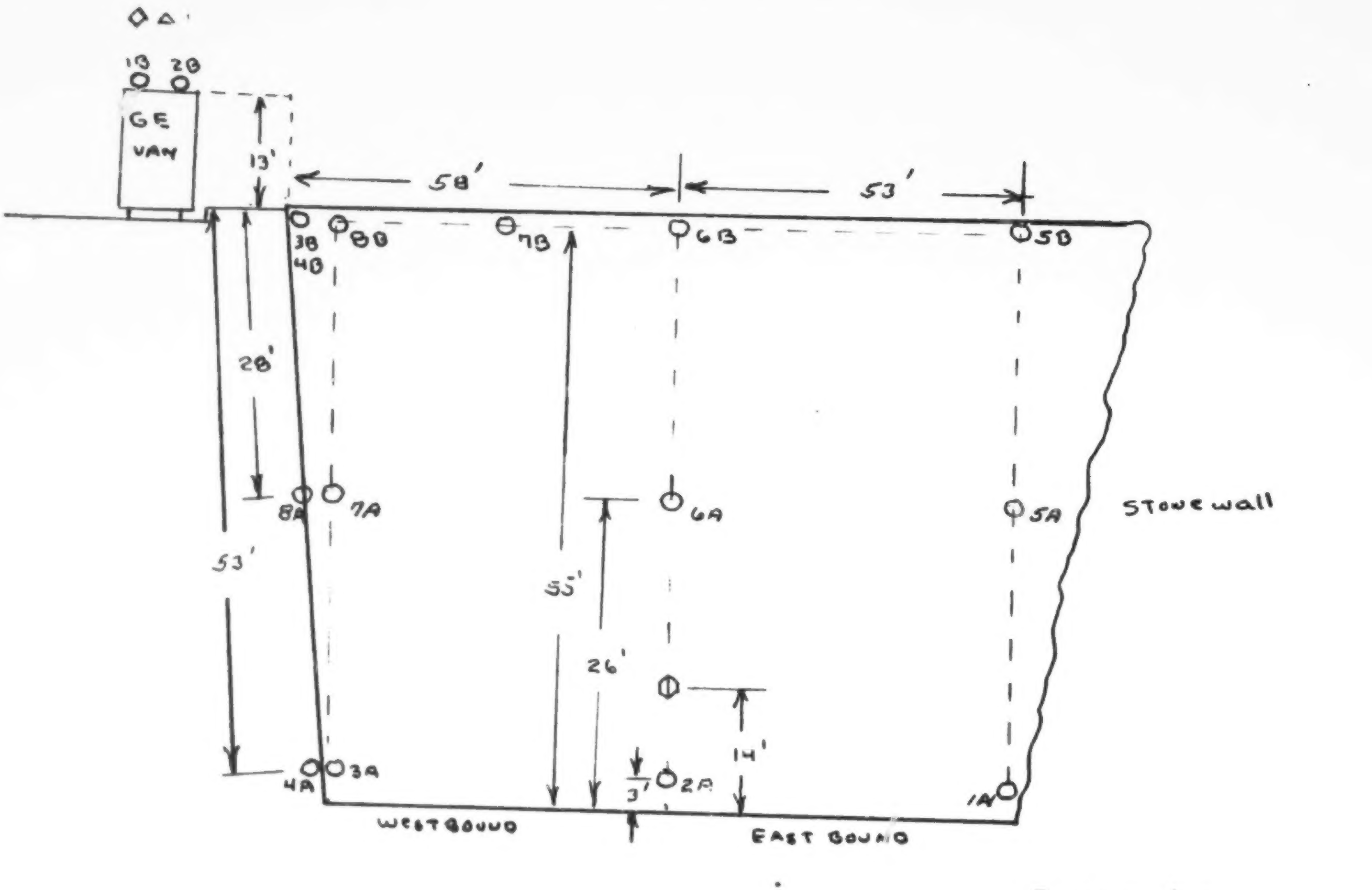
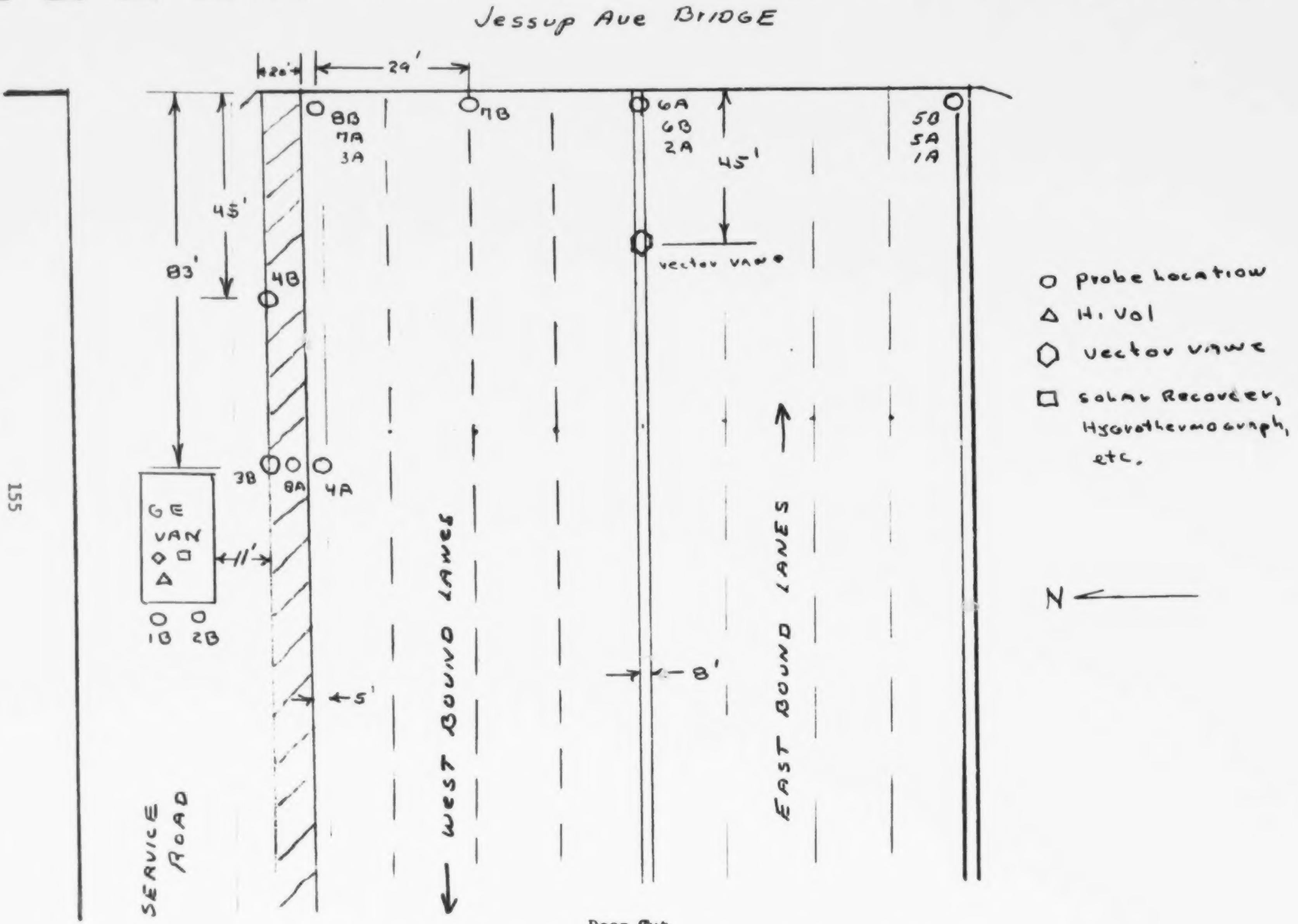
Fig. 4.6-1 Cross Bronx Expressway at Nelson and Jessup Avenues


GE VAN
1B
2B
13'
58'
53'
3B
4B
8B
7B
6B
5B
28'
53'
8A
7A
6A
5A
55'
26'
14'
3'
4A
3A
2A
1A
STONE wall
WESTBOUND
EAST BOUND

○ CO probe
△ Hi Vol
◇ Tape sampler
⬡ Vector vane
☐ Solar Recorder Hygrothermograph, etc.

Deep Cut

Figure 4.6-2 Cross Bronx Expressway at Nelson & Jessup Avenues - Elevation View


Jessup Ave Bridge
20'
24'
45'
83'
8B
7A
3A
7B
6A
6B
2A
45'
vector vane
5B
5A
1A
4B
3B
8A
4A
GE
VAN
◇ □
△
11'
1B
2B
5'
8'
West Bound Lanes
East Bound Lanes
Service Road
○ Probe Location
△ Hi Vol
⬡ Vector Vane
□ Solar Recorder, Hygrothermograph, etc.
N

Deep Cut

Figure 4.6-3 Cross Bronx Expressway at Nelson & Jessup - Plan View

4.6.1.3 Meteorological Conditions

Due to severe sensor damage, mechanical failure problems, and vendor inability to supply immediate replacement parts, it was necessary to use makeshift components, including a hastily fashioned plexiglass tail section. These makeshift components resulted in the sensor being considerably heavier than the design weight. The resultant increase in the inertia of the sensor caused the sigma parameters to be in error for this site. Although values obtained at this site should not be compared to those obtained at other sites, intra-site relationships should remain qualitatively valid.

Wind circulation at this site was very similar to the circulation at the shallow cut site. The wind almost always blew parallel to the sides of the cut as can be seen on Figure C-49. (0° on this chart indicates a wind parallel to the road and blowing toward the George Washington Bridge). Figure 4.6-4[1] illustrates the pronounced effect of the deep cut in translating the general air motion into components parallel to the cut. For example, for all hours that a southeast wind was recorded at Central Park, 94% of the time the wind in the cut was from the east and 6% from the north. In general, flows from the east, southeast and south become easterly at the 14' level of the cut at least 80% of the time. Winds from the southwest, north, and northwest are translated into west for a majority of hours, however their behavior in the cut suggests the presence of a spiral-type eddy under these regimes. General northeasterly winds become disorganized and appear distributed equally between east, south, and southwest. It is possible that tall buildings located along the north edge of the cut disrupt the northeasterly flow over the cut and generate a complex eddy system causing this effect.

Sigma azimuth recorded in the cut, and presented in Figure C-50, is relatively constant over the day. A minimum occurs between 0200 and 0300 but no pronounced maximum can be found during the daylight hours. As expected, and shown on Figure 4.6-5, CO concentration at the site increases as sigma azimuth decreases. (In order to determine the effect of of changes in the horizontal turbulence parameter on carbon monoxide concentration, one average value each for CO at probe #6B [55 feet above the median], total traffic flow rate, and sigma azimuthwere determined for the five weekdays when complete data was available. The daily averages of carbon monoxide concentration and the sigma azimuth parameter were used in plotting the line seen in Figure 4.6-5. This line was determined by linear least squares fit. The total traffic averages were used only as a check to determine whether varying traffic volume was causing the changes in CO levels. Over the five day period, traffic held fairly constant, its

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[1] This figure consists of 8 bar graphs representing the eight octants of a circle, each being centered about the directions: N, NE, E, etc. The "general flow" in each graph represents the wind recorded at the Central Park National Weather Service Station which is assumed to be representative of the general wind direction in the area of the site. The wind directions recorded in the cut are plotted in terms of percentage of total hours from a given direction for each of the eight general wind flows.

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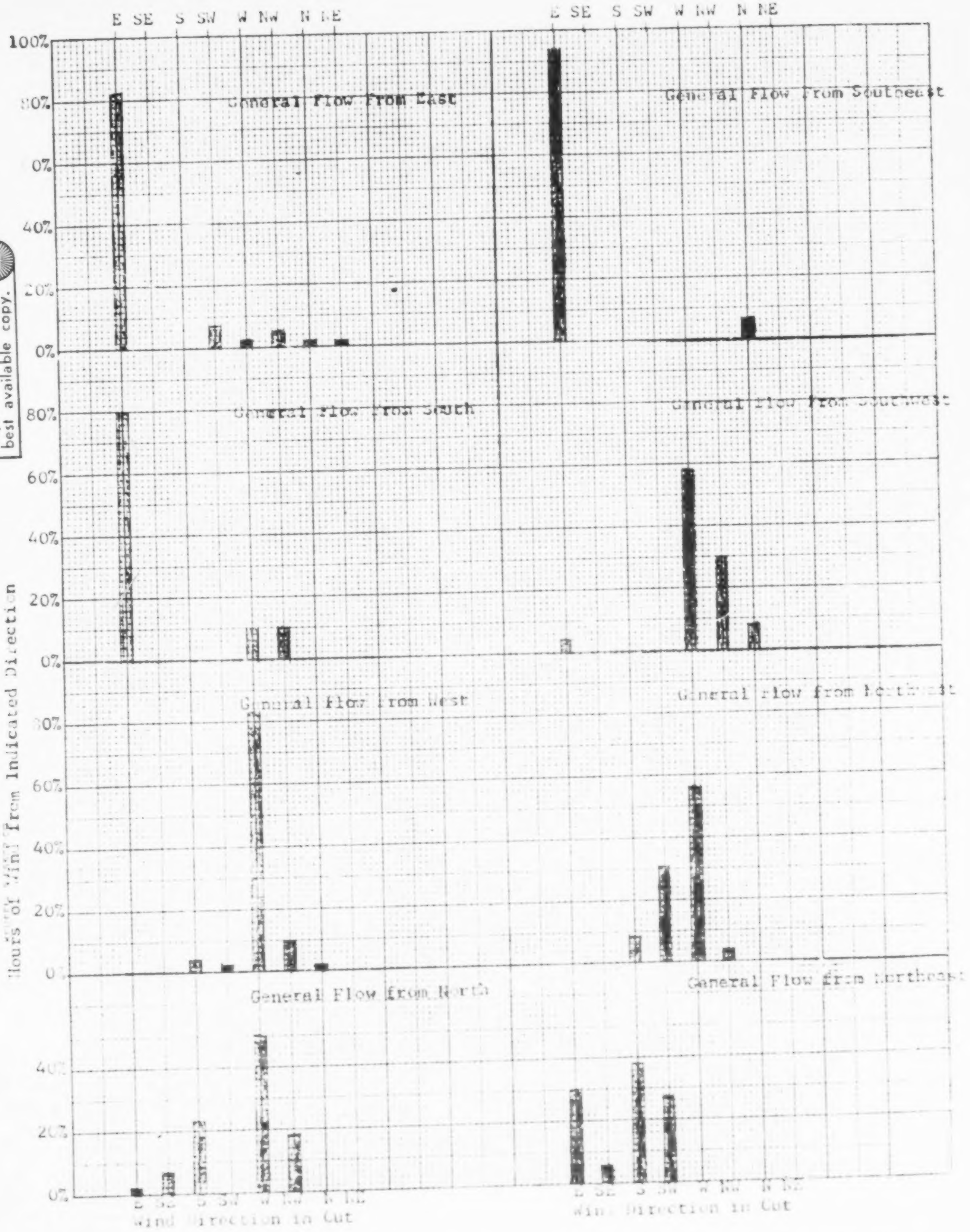


Figure 4.6-4 Relationship of General Wind Flow to Azimuth Recorded in Deep Cut at Jessup Avenue Site

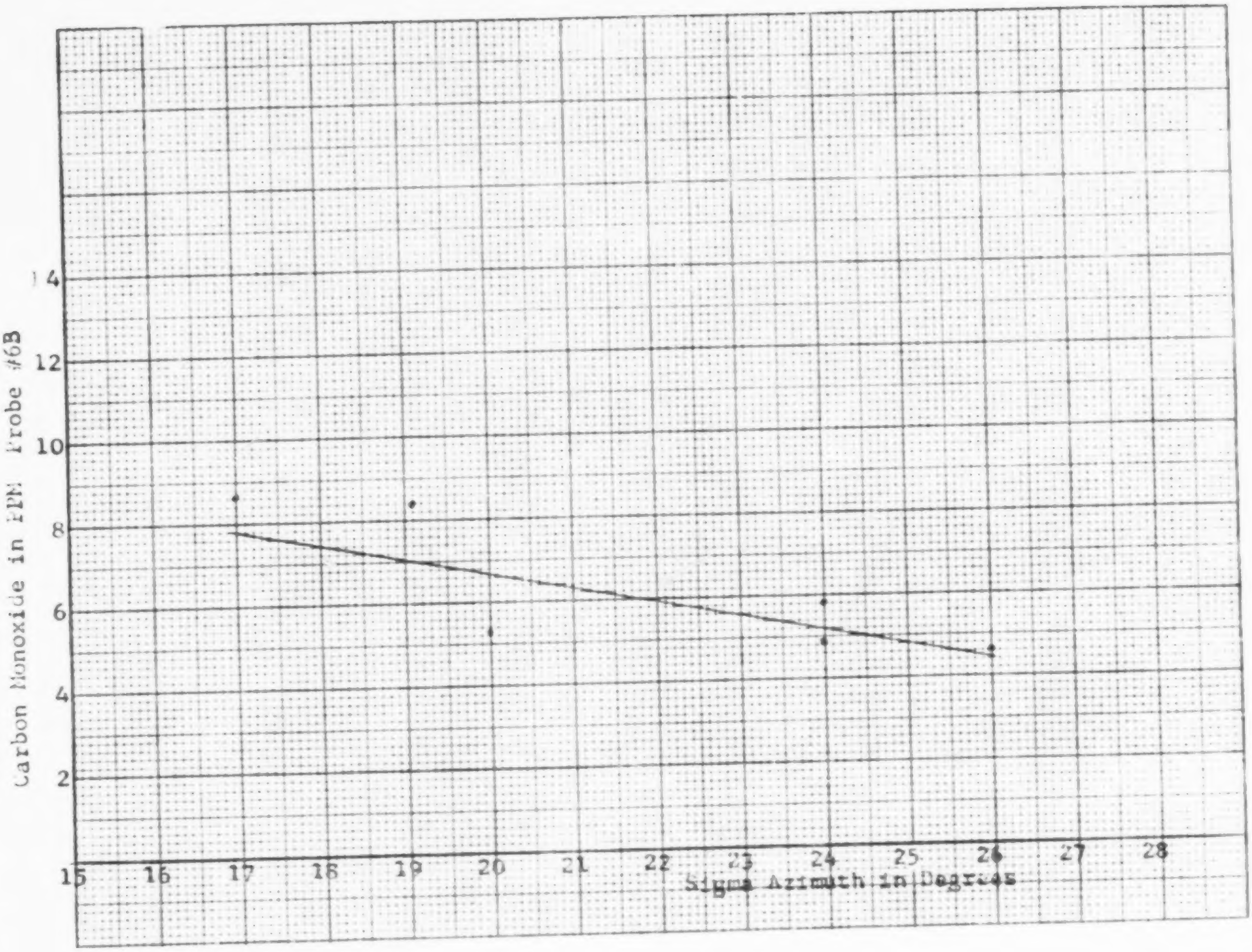


Figure 4.6-5 Sigma Azimuth vs CO Concentration - 5 Weekday Averages - CBE at Jessup

range being 5.2% of the largest value. In contrast, CO and sigma azimuth varied over 47% and 35% of their highest values, respectively. The changes in traffic can therefore be considered small compared to the changes in the other two quantities. This allows traffic to be considered a constant for this particular set of points. The exact form of the relationship at this site, however, cannot be determined from these few points.)

The prevailing wind elevation angle recorded in the cut is about -5°, indicating that air moved downward more often then up and out of the cut. This angle, however, is very small and the previously discussed emergency repairs to the wind system as well as precipitation effects cast doubt upon its validity. An additional indication of a slightly out-of-balance sensor is the tendency for elevation angles to become larger in a negative direction during the calm hours of the early morning such as on March 19, 21, and 23. (See Table C-64).

Sigma elevation recorded at this site is plotted in Figure C-66. The curve is very similar in shape to the sigma azimuth curve. Hourly data on most days also follows the same pattern and thus retains about the same relationship to concentration as that for sigma azimuth.

Winds were generally light with only 10 hours out of more than 200 in excess of 10 mph. The average wind speed was 5.5 mph. The hourly wind speed curve, presented in Figure C-53, has a minimum between 0300 and 0400 and a maximum between 1400 and 1500.

4.7.1 Bruckner Expressway Near White Plains Road

4.7.1.1 Site Description

Bruckner Expressway extends from the Tri-borough Bridge to the Throgs Neck Bridge in the Bronx, carrying six lanes of two-way traffic. The "Grade Road" site chosen for this study was located along this expressway between White Plains Rd. and Castle Hill Rd. Figure 4.7-1 shows the test site, looking east.

The most important characteristic of this site was the fact that it is completely open. There were no natural or man-made obstacles such as walls, buildings, etc., to interfere with the wind currents and normal CO diffusion patterns. There was, however, a metal sign structure spanning the entire roadway at this point. A total of 8 lanes of traffic flow beneath the sign structure with two of the lanes being an exit and an entrance lane to and from parallel service roads adjacent to the expressway.

Approximately 55,000 vehicles travel on Bruckner Expressway daily at an average speed of 48 miles per hour. The traffic flow southbound peaks at an average of 2140 vehicles during the morning rush hour. The evening rush hour produces a northbound average traffic peak of 2550 vehicles. Average total daily traffic southbound is about 25,000 vehicles while the northbound average exceeds 29,000 vehicles daily.

4.7.1.2 Instrumentation Arrangement

Figs. 4.7-2 and 4.7-3 show the probing scheme and associated site information. The GE trailer was parked on the south service road which ran parallel to the expressway. The overhead sign structure was utilized to position the various CO probes relative to the roadway.

Twelve probes were used to monitor CO concentration adjacent to the roadway. CO probing ran overhead from the GE trailer to the supporting metal framework. Three probes were positioned at the North, Center and South sides of the roadway at 3', 14' and 25' above the roadway. One probe was also placed at the center 25' above each direction of traffic. One probe was 20' above the service road on which the trailer was situated.

A Hi Volume Particulate Sampler, solar recorder, Tape Sampler, and hygrothermograph were on the roof of the trailer.

Hydrocarbon concentrations were monitored by utilizing all the probes and were average site values.

Meteorological readings were taken with two vector vane systems. Vane 1 was located on the south corner of the sign structure, 30' above ground level. Vane 2 was located, as was customary, 14' above the medial barrier and approximately 20' east of the sign bridge. The sign structure was of an open type construction and should have had only minimal effect on the wind parameters as measured by Vane 2.

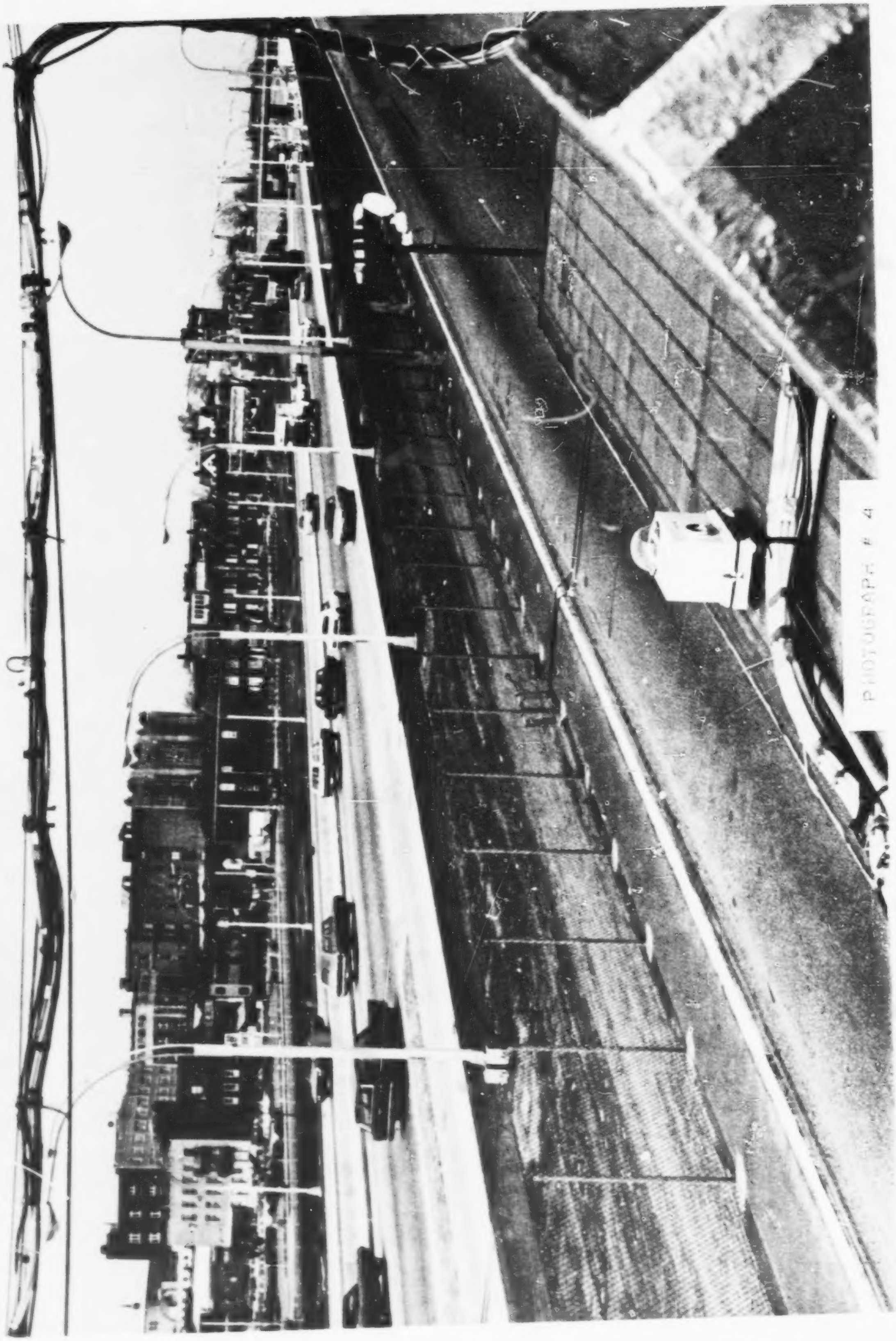

PHOTOGRAPH # 4

Fig. 4.7-1 Bruckner Expressway Near White Plains Road

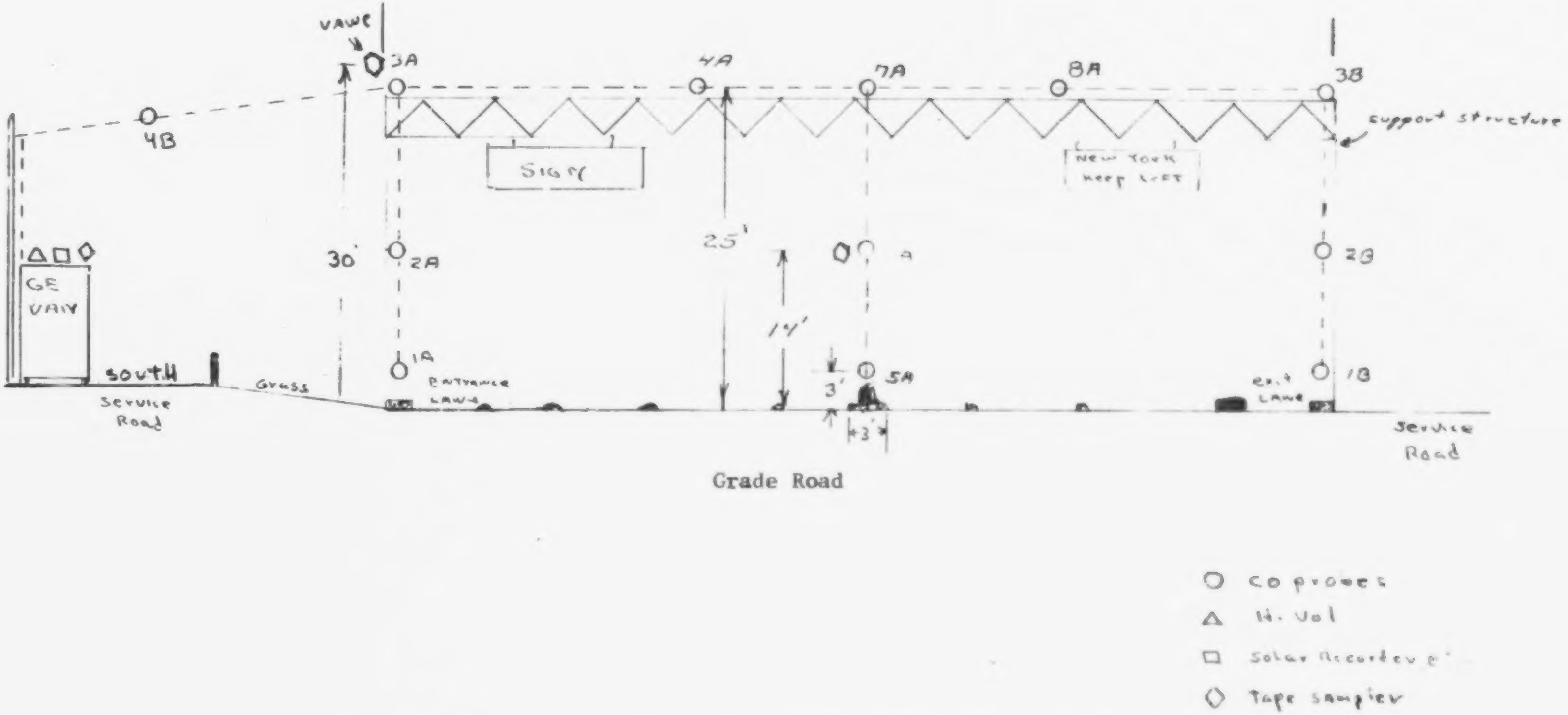

VANE
3A
4A
7A
8A
3B
support structure
4B
SIGN
NEW YORK
KEEP LEFT
30'
2A
25'
14'
2B
GE VAN
1A
ENTRANCE LANE
3'
5A
exit LANE
1B
SOUTH
Service Road
Grass
3'
Service Road
Grade Road
○ CO probes
△ H. Vol
□ Solar Recorder
◇ Tape sampler

Fig. 4.7-2 Bruckner Expressway Near White Plains Road - Elevation View

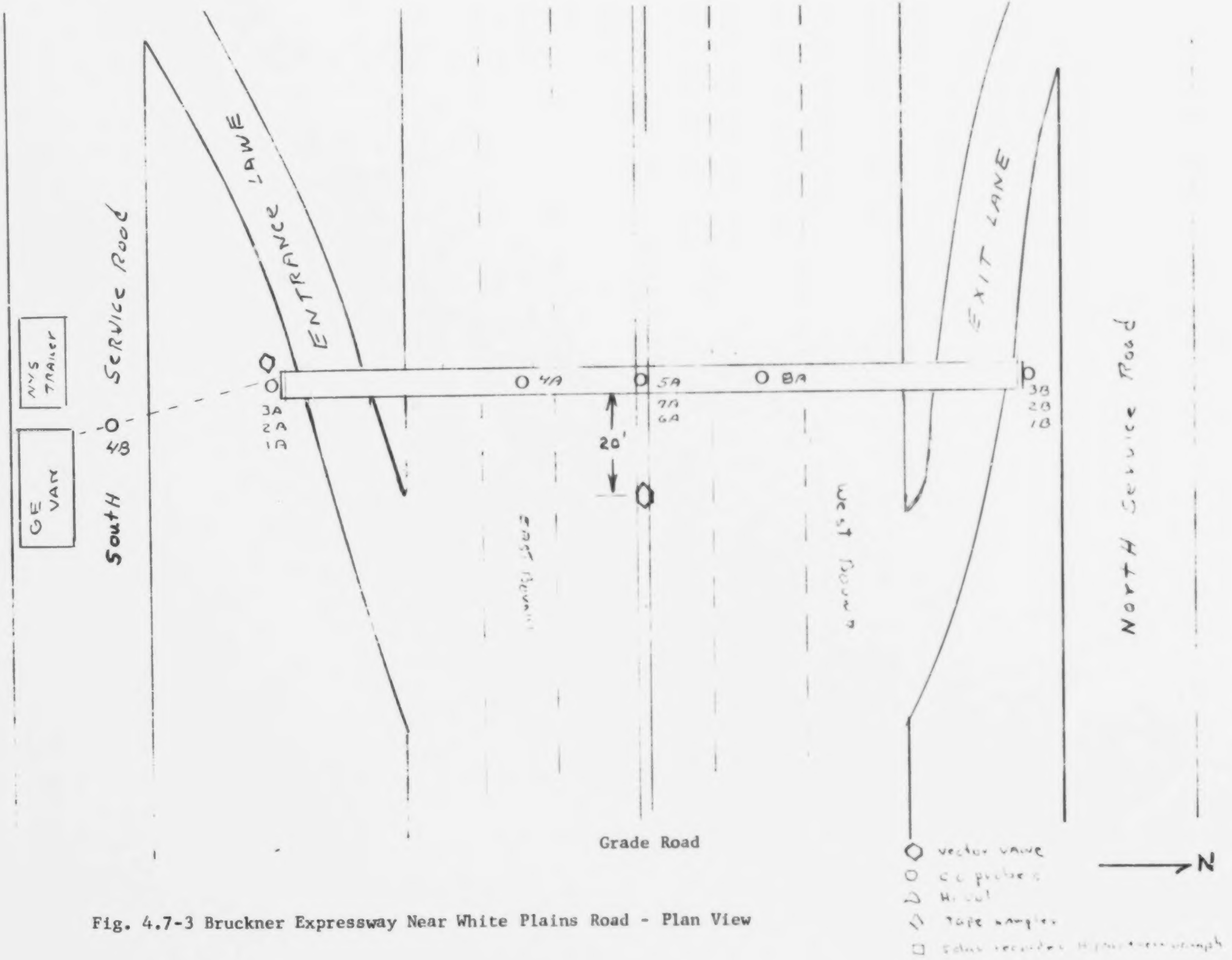

South Service Road
ENTRANCE LANE
NYS Trailer
GE VAN
4B
3A
2A
1A
O 4A
5A
7A
6A
O 8A
20'
3B
2B
1B
East Bound
West Bound
EXIT LANE
North Service Road
Grade Road
vector vane
CO probes
Hi vol
Tape samplers
Solar recorder Hygrothermograph
N

Fig. 4.7-3 Bruckner Expressway Near White Plains Road - Plan View

4.7.1.3 Meteorological Conditions

Wind data was taken at this site from April 8 through April 22. Minimum problems were experienced with the measuring equipment. All data taken at this site is presented in Tables C-71 through C-90 and Figures C-57 through C-72. (Zero degrees azimuth at this site indicate a wind parallel to the Bruckner Expressway and blowing from the west.) The prevailing azimuth direction recorded at vane 1 was from 175°; or from the east. The hourly directions recorded at this vane agree very well with the general wind over the New York City area. This is due to the openness of the site and the height of the sensor above ground level.

No consistent southerly winds occurred during the operational period of vane 1, eliminating the possibility of a quantitative investigation of eddy effects caused by a large apartment structure to the south of the monitoring location. This eddy was visually observed, however, in an experiment performed on April 9 when the wind was generally south to southwest over the site. A small gas filled balloon of approximately neutral buoyancy was released in an area to the north of the apartment building where rising air had been noted earlier. This balloon was carried to the top of the building and then downward and away from the building, finally to return to its release location by moving near ground level back toward the building. This circuit, describing the size and shape of the eddy at the lee side of the building was repeated several times until the balloon finally left the eddy and entered the main southerly air flow by penetrating the separation layer at roof level. It was then carried downward and toward the northeast, reaching ground level at the approximate location of the median on the Bruckner Expressway. The fact that the eddy does not quite reach the location of the wind sensor on the median strip may be seen in the data from April 8 and 9 which shows southerly winds at the medial barrier location.

The sigma azimuth curve for vane 1, shown in Figure C-58, is quite flat with small maxima near 0900 and 1800 and a minimum near 0400. Sigma azimuth for vane 2, closer to the ground and to moving traffic, was, on the average, higher but still maintained the same flat characteristic.

The sigma elevation turbulence parameter at the medial location also shows very small range in its mean values. The readings were virtually the same from 0600 through 2400. Sigma elevation recorded at the higher vane showed considerable more variation with time of day, having a broad maximum during the daylight hours and a minimum between 0300 and 0400 hours.

Determination of any relationship between turbulence parameters and pollutant concentrations at this site was very difficult due to the extremely small values and limited range of the CO concentrations and the small range of turbulence measurements. Turbulence, however, was considerably above the mean on four days during the monitoring period. On one of those days, Saturday April 18, meteorological conditions which were unusual may be used to gain insight into the meteorology-pollutant relationships at this site. Figure 4.7-4 is a plot of sigma elevation from vane 1, carbon monoxide as measured at the trailer, and total traffic all

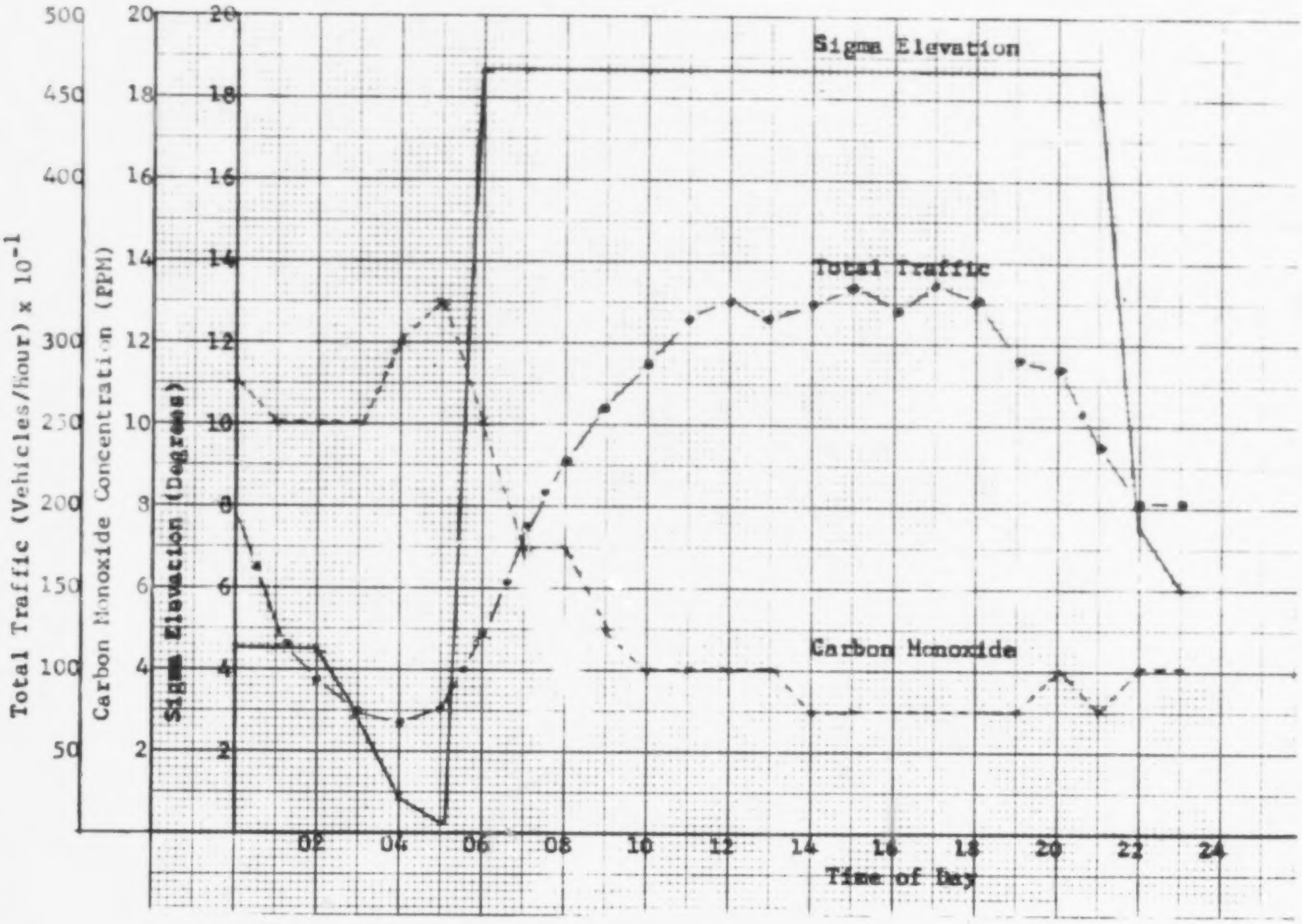


Figure 4.7-4 Turbulence - Traffic - Pollutant Relationship
Saturday, April 18, 1970 - Bruckner Expressway

plotted against time. (The trailer probe location was chosen in this case because it is near a living area and serves to illustrate the adverse effects that may occur downwind from a source under certain meteorological conditions. Upwind probes, those on the north side of the expressway, showed the same pattern but to a lesser extent.) As can be seen in this figure, carbon monoxide levels in front of the apartment structure appear virtually independent of traffic volume on this particular day. This is a result of the immense change in atmospheric stability occurring at 0600, masking any traffic effect on CO levels. Accompanying the very sharp increase in sigma elevation was a corresponding increase in sigma azimuth and wind speed. The sharp decrease in CO concentration was due to vigorous mixing and not a different air trajectory. It is interesting to note that the value of 13 ppm reached during the calm at 0500 was met or exceeded only 6 hours at this location during the entire monitoring period.

The diurnal wind speed patterns recorded at the two vector vanes are similar. A minimum occurs in the early morning and a broad maximum over several hours at mid-day. A small indication of a double peak occurs in this maximum but it is probably not traffic induced. The range of mean wind speed values was among the largest of any site, being 4.6 mph for the 30' vane (vane 1). The highest wind speed recorded was 20.8 mph at 0900 and 1000 on April 15. The average wind speed of 8.1 mph was the highest wind speed of any site. The large ranges and high averages are due to the open configuration of the area. Wind speed decreased from the 30' vane to the 14' median vane. Apparently any traffic generated wind velocity at this site is not enough to overcome the normal downward decay of wind speed associated with the logarithmic wind profile.

4.8.1 Grand Central Parkway at Parson's Boulevard

4.8.1.1 Site Description

The Grand Central Parkway, at Parson's Boulevard in Queens, becomes a subsurface roadway and is part of a unique roadway structure not often encountered. The roadway is partially covered on both sides by two elevated service roads. A total of six lanes of traffic flow within this configuration. The four inner lanes are uncovered while the two outside lanes are sheltered by two cantilevered sections. Adjacent to each traffic direction is a 8' pavement and a 4' medial barrier. Figure 4.8-1 shows the roadway configuration at the test site.

The Parkway carries approximately 110,000 cars per day. Average speed is 45 miles per hour. The eastbound lanes carry 57,000 cars with an average weekday peak volume of 6,000. The westbound lanes carry 53,000 cars daily with a 6,120 average peak. No truck traffic is permitted. The parallel service roads carry 23,000 vehicles per day.

4.8.1.2 Instrumentation Arrangement

The GE Air Pollution Van and the New York State Traffic Trailer were parked along the North Service Road adjacent to the Queens Hospital. Nine probes were used to monitor the CO concentration on the parkway as shown in Figures 4.8-2 and 4.8-3. These probes were 3', 10' and 20' off the roadway. One set was along each site of the double cantilever structure while the third set was along the median strip. Three other probes sampled CO concentration 20' over the adjacent service roads. CO was also monitored directly outside the GE trailer (probes 6B & 7B).

Two probes were used to provide data on the indoor-outdoor CO relationship at the hospital. One of these was placed inside the nurses quarters on the 4th floor. The other was located on the outside of the hospital at the same elevation.

Two weather vanes were installed at this site to measure meteorological conditions. The road vector vane (vane 2) was 25' west of the probe plane along the median strip at a height of 14'. Another vane (vane 1) was located on a pole on the wall separating the North Service Road from the Parkway across the street from the GE trailer at a height of 25' above the service road.

One Tape Sampler and one Hi Vol were located on the GE trailer and a second tape sampler was placed inside the nurses quarters on the 3rd floor.

4.8.1.3 Meteorological Conditions

Wind data was acquired at this site for the period April 27 through May 11. The data and associated statistics for this site are pre-

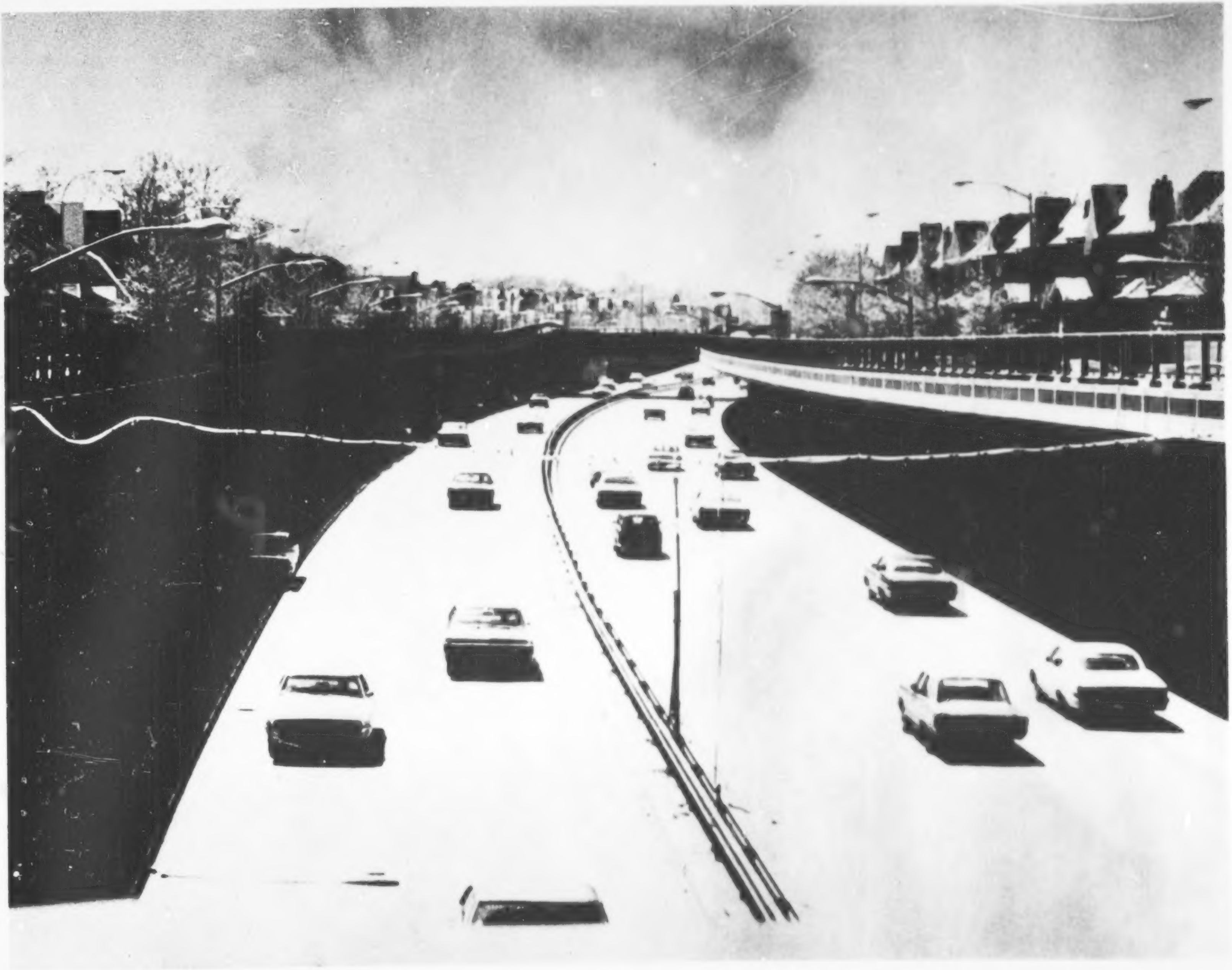
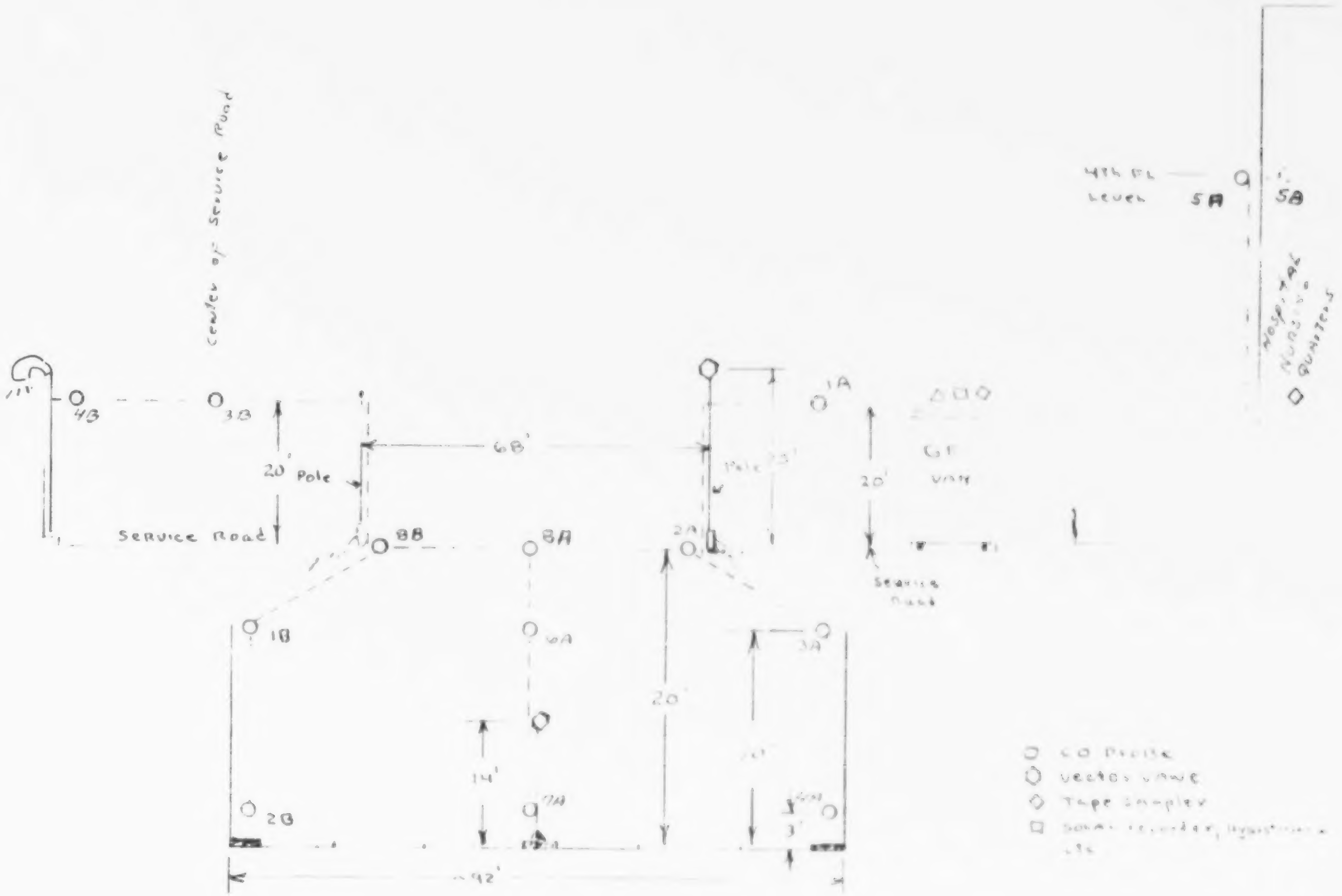


Fig. 4.8-1 Grand Central Parkway at Parson's Boulevard


Center of Service Road
4B
3B
20' Pole
Service Road
68'
8B
8A
1B
6A
2B
14'
7A
92'
Pole 23'
1A
2A
3A
20'
20'
3'
6A
20'
GE
VAN
Service Road
4th FL
LEVEL
5A
5B
Hospital
Nurses
Quarters
CO Probe
Vector Vane
Tape Sampler
Sound recorder, hygrothermograph
etc.

Double Cantilever Covered

Fig. 4.8-2 Grand Central Parkway at Parsons Boulevard - Elevation View

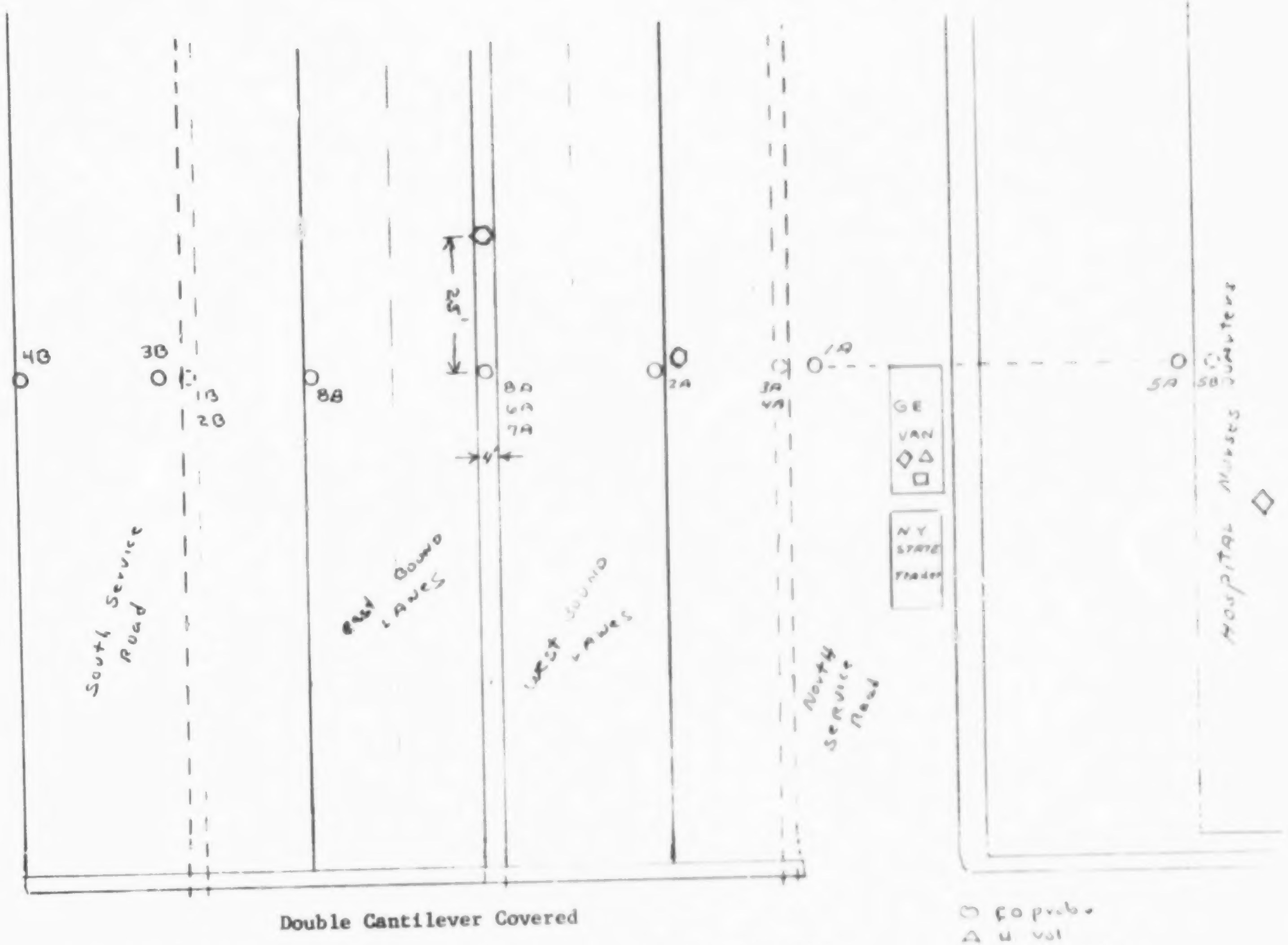

4B
3B
1B
2B
8B
25'
8A
6A
7A
4'
2A
3A
4A
1A
5A
5B
GE
VAN
NY STATE Trailer
HOSPITAL Nurses Quarters
South Service Road
East Bound Lanes
West Bound Lanes
North Service Road
Double Cantilever Covered
○ CO probe
△ W vel
◇ Tape sampler
□ Sound recorder

Fig. 4.8-3 Grand Central Parkway at Parsons Boulevard - Plan View

sented in Figures C-73 through C-88 and Tables C-91 through C-110 in Appendix C.

The predominant azimuth reading recorded at the service road was 0°. (The 0° reference for both vanes at this site represented a wind parallel to the Parkway and from a generally westerly direction.) Virtually no wind was recorded from 50° to 160°, as Table C-92 illustrates. This is due to a combination of factors. First, Queens Hospital, located just to the north of the service road, shielded the sensor from any direct exposure to a northerly wind. Second, wind flow over the city during the monitoring period was from the north on only 11 out of 360 hours, as determined from National Weather Service records from the Central Park Station. Finally, northeasterly winds over the area were channeled parallel to the street and easterly in the locality of the sensor and northwesterly winds were chanelled parallel to the street, and therefore westerly. Winds from the southerly quadrants did occur, as the topography was open to the south of the sensor.

The sigma azimuth curve for the service road sensor shows a typical diurnal pattern. The minimum occurs between 0400 and 0500 hours and, after a fairly steady increase in turbulence through the morning and early afternoon, the maximum occurs near 1600 (see Figure C-74). A calm period similar to that discussed for the Bruckner Expressway was encountered early in the morning of April 25. Values of sigma azimuth dropped to less than one degree early that morning. Wind velocity also dropped to near zero. This stagnation of atmospheric motion caused a considerable buildup of carbon monoxide in the air above the Parkway. This is evidenced in the concentration measured at probe 3B, over the eastbound service road. Concentrations at this probe over these morning hours were among the highest recorded any day at those same hours and were approximately twice the mean values. The same effect was also seen inside the cut where concentrations at probe 4A, north wall - 3 foot level, ran between two and three times the mean levels. This was not a traffic-induced phenomenon, as the total traffic volume in the early morning hours of April 29 was at or below mean values.

The elevation angle frequency of occurrence data in Table C-95 indicates that, on the average, the wind at the vane located over the service road had a slight downward component of about 5°. No dependence of the elevation angle on horizontal wind direction can be found for this sensor. Some dependence on wind speed is noted, but this is probably due to the magnification of errors associated with the sensor balancing in low-wind velocity conditions.

The vertical turbulence parameter, sigma elevation, as recorded by vane 1, is similar in its trends to the sigma azimuth channel. The minimum of the sigma elevation curve occurs between 0300 and 0400, and the maximum near 1600.

Wind speeds over the service road were, on the average, quite low compared with previous sites. The average for all hours was 3.7 mph. Calm or near calm conditions occurred several mornings, including April 29, May 1, 9, and 11. Except for the morning of May 1, these stagnant conditions were associated with significantly elevated carbon monoxide concentrations. Figure C-77, which is a plot of wind speed over an average day at this sensor location, shows a typical diurnal curve with the minimum during the early morning and the maximum occurring during the time of maximum surface temperature, at about 1500.

The prevailing azimuth angle recorded by vane 2, located in the partially covered cut, was 125°. Wind never blew from this direction above the cut. The azimuth frequency distribution was evenly spread from 130° through 300°; however, there were virtually no hours of wind between 0° and 110°. These facts indicate that the azimuth at this site behaved differently from that at any other cut. This is undoubtedly due to the fact that this cut was partially covered. It appears that a great deal of the external influences on the wind in the cut were effectively removed by the partial cover.

Sigma azimuth values in the cut were higher than those measured over the service road by about 2°. It is also noted that the azimuth traces tended to wander over large angular deviations - direct result of the lack of a strong steering effect by synoptic winds. This is one of the causes of the higher sigma azimuth. Although the weather-induced trends that were measured by vane 1 are apparent to a limited extent, the calm periods of the early morning hours are no longer as calm - an effect of moving traffic close to the vane. The diurnal pattern of the sigma azimuth values in the cut also differs from the pattern recorded on the service road. No longer is there a smooth transition from minimum to maximum. Instead, there is a new second maximum between 0800 and 0900. The minimum remains near 0400, but the afternoon maximum is shifted one hour later to 1700. The morning maximum is real. An examination of the standard deviation curve in Figure C-82 (dashed line), as well as comparisons with the standard deviation curve for vane 1, support this statement. The double-peaked feature is caused by the influence of moving traffic on the surrounding atmosphere. Figure 4.8-4 is a plot of the total traffic and sigma azimuth diurnal cures. There is a great deal of similarity between the two curves with minima and maxima occurring within one hour of each other.

The Grand Central Parkway is the only site where turbulence parameters showed a distinct double peak attributable to the traffic maxima during the morning and evening rush hours. Other closed sites, such as the two tunnels, should also show a very strong correlation between traffic and sigma azimuth but, as was indicated previously, it was impossible to monitor inside the tunnels.

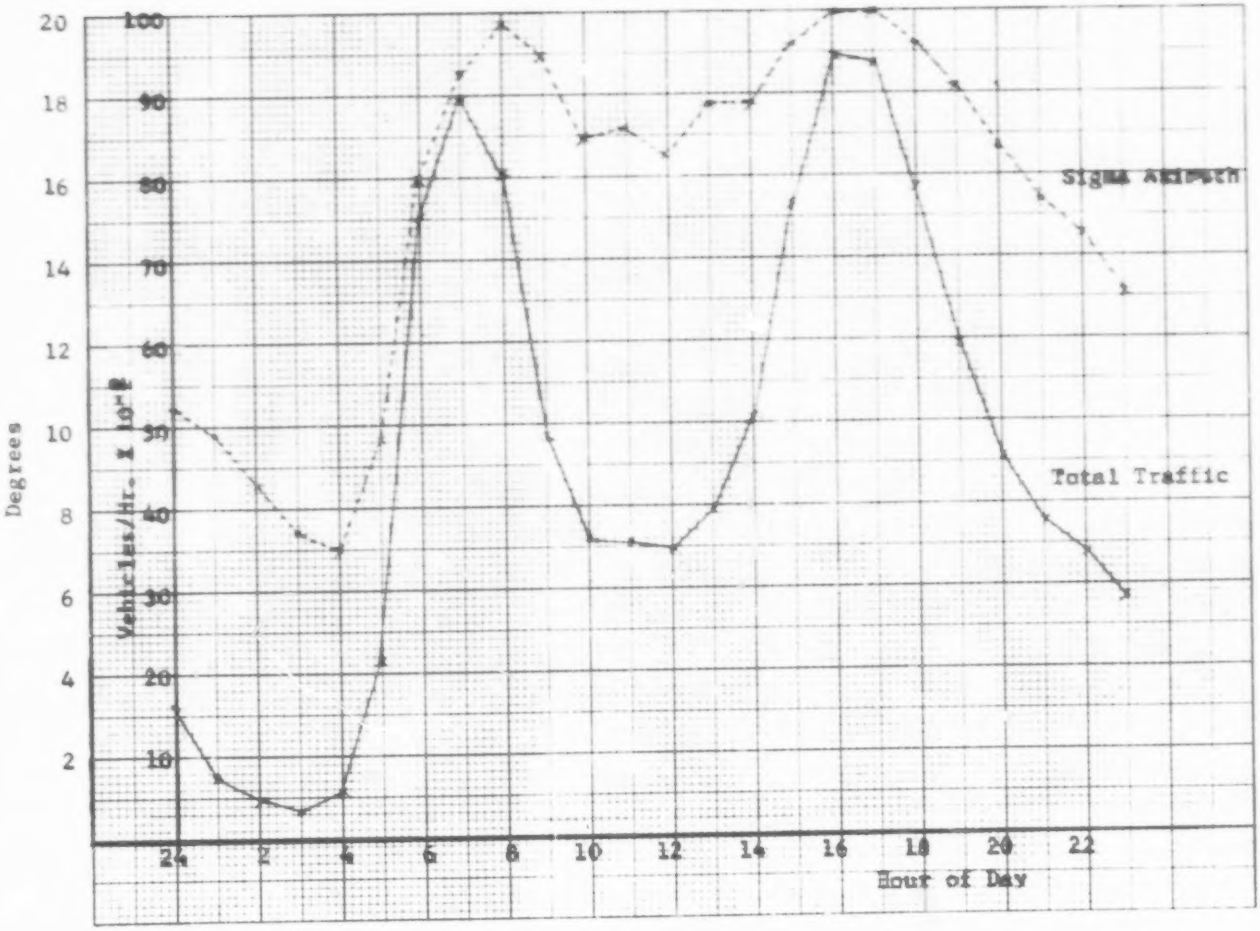


Figure 4.8-4 Sigma Azimuth and Total Traffic at Grand Central Parkway

The sigma elevation curve for the medial barrier location is similar to the sigma azimuth curve. The double maximum is again present in the morning and afternoon hours. The minimum of the curve occurs between 0300 and 0400, and a relative minimum occurs near noon.

Elevation data recorded by this sensor indicates the center of the frequency distribution to be near -15°. Only 0.7 percent of the monitoring hours had elevation angles greater than 0°.

Wind velocities recorded in the cut were quite low. The mean wind speed for all monitoring hours was 2.5 mph. This compares with 3.7 mph measured on the service road. The highest hourly wind velocity recorded was 7.0 mph between 1000 and 1100 on May 6. Mean wind speed shows no evidence of a traffic-induced double peak. The maximum occurs between 1500 and 1600 hours, and the minimum between 0300 and 0400.

4.9.1 Brooklyn Queens Expressway at Park and Navy Streets

4.9.1.1 Site Description

At this point in Brooklyn, the Brooklyn Queens Expressway becomes an elevated six lane highway. The roadway is ~30 ft. above ground, being supported from beneath by heavy steel pillars. The total width of the structure is ~93 ft., having 4 ft. curbs and a 7 ft. medial strip. Two service roads ran parallel to the elevated highway at ground level. The test location is shown in Figure 4.9-1.

108,000 vehicles travel on the expressway at this point each day at an average speed of 38 mph. The northbound lanes carry approximately 56,000 vehicles per day, reaching an average peak hourly traffic volume of 3910 vehicles. About 52,000 vehicles travel the southbound lanes daily. The southbound peak traffic is 3750 vehicles. The parallel service roads at grade carry an additional 11,500 vehicles per day.

The site is relatively open. An elementary school is located ~ 200' to the south of the expressway and a park area is situated to the north.

4.9.1.2 Instrumentation Arrangement

The G. E. trailer was parked beneath the viaduct between the support pillars. The sampling probe array used for CO is shown on Figures 4.9-2 and 4.9-3.

Five CO probes were placed above the highway to monitor CO concentrations in a plane perpendicular to the roadway. These highway probes were 10' and 20' off the surface of the roadway. Other probes were placed at various vertical and horizontal distances from the roadway in order to determine CO levels at points remote from the highway. The open area surrounding the site permitted probes to be placed as far as 200' from the roadway.

Two wind sensors were placed on the elevated portion of the BQE at this site. One sensor, vane 1, was located on the probe supports at the north edge of the road. This vane was elevated 20' above the road surface which, itself, was 27' above the ground. Vane 2 was located on the medial barrier and 14' above the road surface. Both wind sensors were in the probe plane. One tape sampler was located on the roof of the GE trailer while another sampled inside a nearby hospital at roof level. A high Volume Air Sampler was located on the roof of the hospital. No Hi Vol samples were taken at the trailer due to vandalism of equipment.

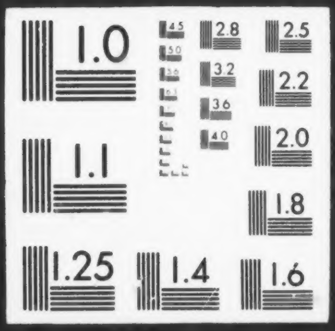
4.9.1.3 Meteorological Conditions

The wind monitoring period comprised 17 days from May 18 through June 3. Reliable data was obtained from most wind channels during

3 OF 3

PB

211 235


1.0
4.5
5.0
5.6
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

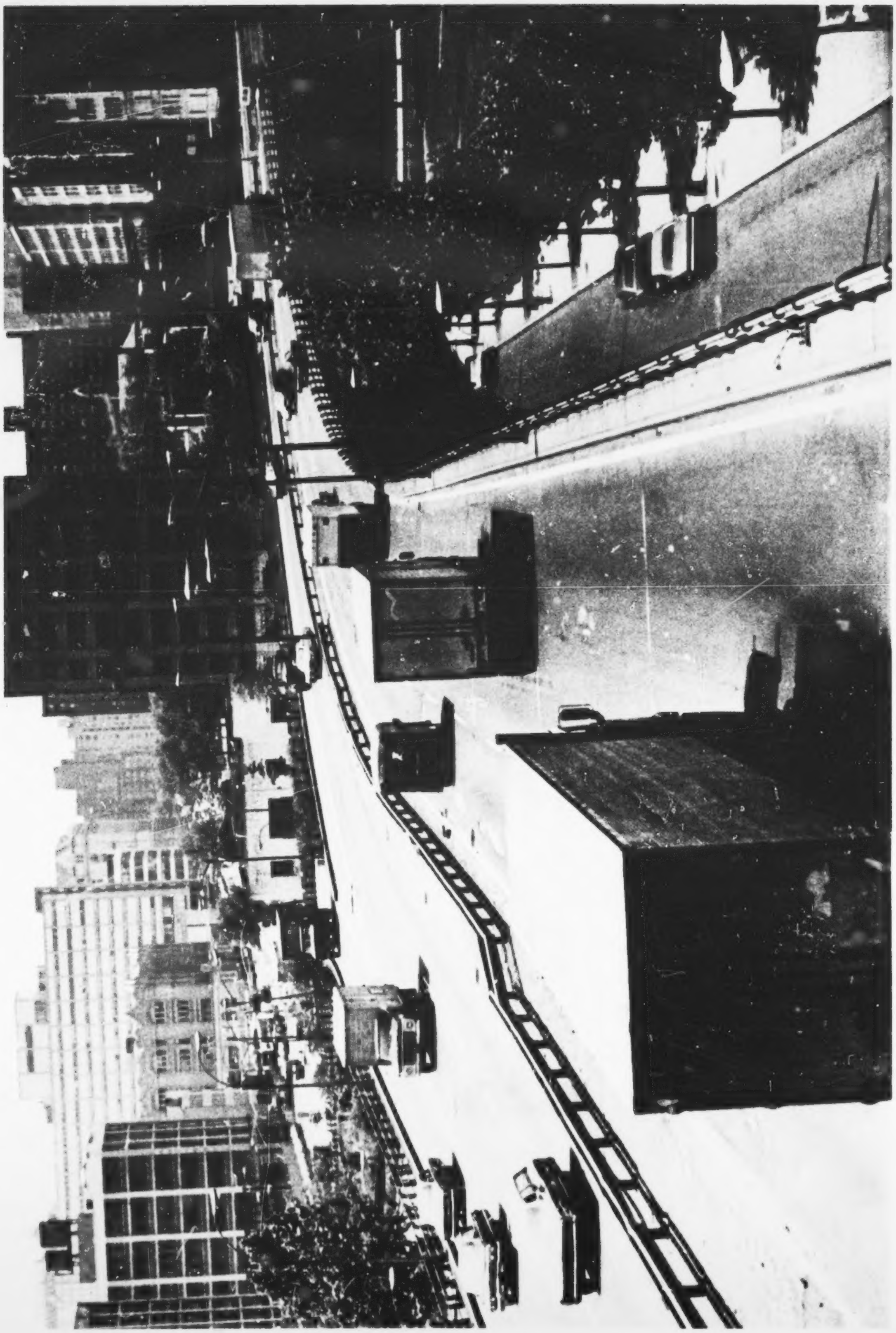


Fig. 4.9-1 Brooklyn Queens Expressway at Park and Navy Streets

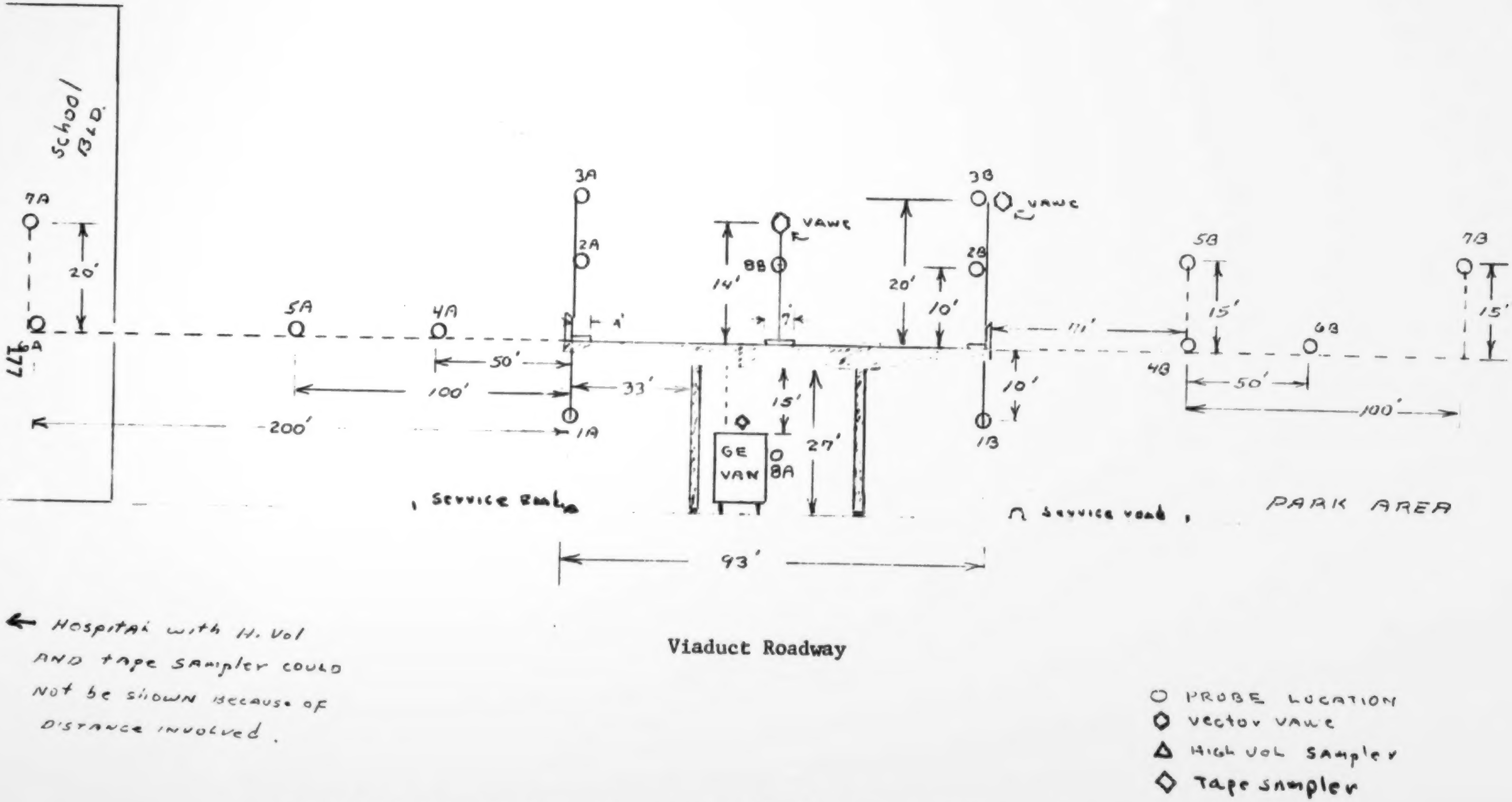

School BLD.
7A
20'
6A
5A
4A
3A
2A
1A
4'
50'
100'
200'
33'
VAWE
8B
14'
7'
15'
27'
GE VAN
8A
3B
2B
1B
20'
10'
10'
11'
5B
4B
6B
7B
15'
15'
50'
100'
Service Road
Service road
PARK AREA
93'
Viaduct Roadway
← Hospital with H. Vol AND tape sampler could not be shown because of distance involved.
○ PROBE LOCATION
⬡ Vector VAWE
△ High Vol Sampler
◇ Tape sampler

Fig. 4.9-2 Brooklyn Queen Expressway at Park and Navy Streets - Elevation View

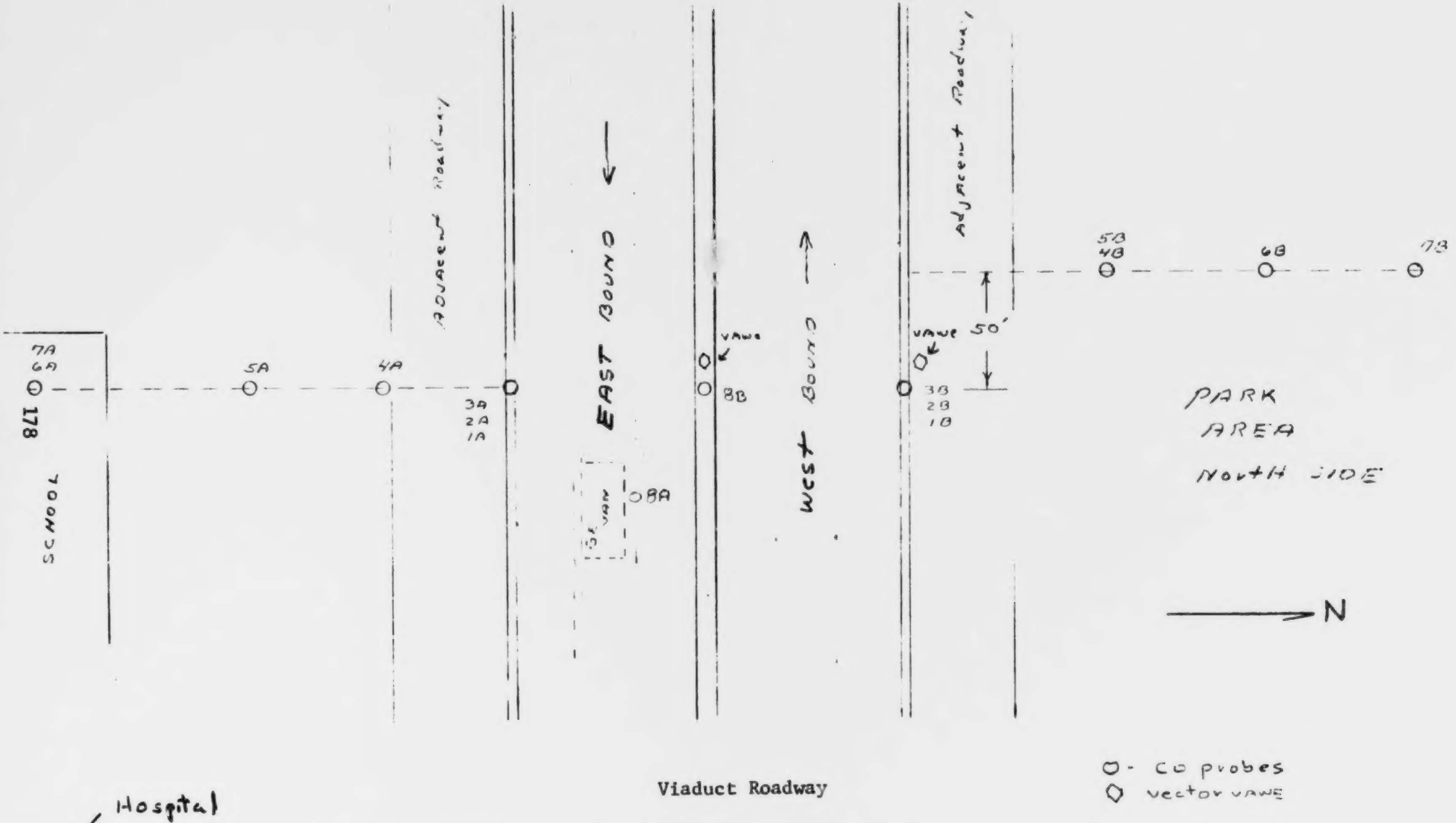

7A
6A
5A
4A
3A
2A
1A
SCHOOL
Adjacent Roadway
EAST BOUND
0BA
3E VAN
VAWE
8B
WEST BOUND
VAWE
50'
3B
2B
1B
Adjacent Roadway
5B
4B
6B
7B
PARK
AREA
North SIDE
N
Viaduct Roadway
O - CO probes
⬡ vector VAWE
Hospital

Fig. 4.9-3 Brooklyn Queen Expressway at Park and Navy Streets - Plan View

this period, broken only by short duration interruptions. Some data was missed in the wind speed channel of vane 1 and the elevation and sigma elevation channels of vane 2 due to malfunctions requiring a longer time to correct. The means of the ventilation parameters, (i.e. wind speed, sigma azimuth and sigma elevation), were comparatively low at this site, indicative of the approaching summer weather conditions.

The azimuth angles as recorded by vane 1 at the 20' elevation show the frequency of occurrence to be spread evenly over all 360° except for one spike at 75° (Figure C-89). (A 75° wind in the coordinate system of this site would correspond to a synoptic wind from 360° or north.) The majority of readings taken at Central Park during the monitoring period indicate a wind from northerly quadrants, agreeing with measurements taken at this site.

The mean sigma azimuth values recorded at the 20' location vary very little over a 24 hour period. The minimum of 6.9° occurs between 0300 and 0400 hours. The maximum of 11.6° occurs between 1200 and 1300 hours (Table C-113).

The frequency distribution for the elevation angle, as recorded by vane 1, shows the prevailing elevation to be centered about -5° (Table C-115). The effect of precipitation on the balance of the vector vane sensor may be seen by examining the elevation data from this vane. Rain was reported by the field crew on May 23, 24, 25, and 26. The elevation data for those days showed several hours with strongly negative readings such as -30.4° at 1100 on the 25th and -52.6° at both 9300 and 0400 on the 26th. Low wind speeds such as .8 and .4 mph at 0300 and 0400 on the 26th allowed the wet sensor to hang with the tail at almost maximum negative elevation.

Sigma elevation recorded by vane 1 had a somewhat limited range of 3.2° in the mean values. The minimum occurred at 0400 and the maximum at 1500. As expected, because of this sensor's distance from traffic and openess of the site configuration, the sigma curves bear little resemblance to the double peaked traffic curves for this location.

Wind speed at the vane 1 location was light, with the average for all hours being 3.3 mph. The highest speed was 10 mph on May 27 at both 1300 and 1700. The wind velocity plot, as seen in Figure C-93, is different from most others in that, while the maximum is where it should be -- in the afternoon, the minimum occurs about four hours earlier than expected at 0100.

Wind azimuth as measured by vane 2, on the median, was even more uniformly distributed than that measured by vane 1. No 10° interval contained more than 9 percent of the total observations (Table C-122). It is likely that a lack of definite and extended duration synoptic wind patterns during the monitoring period caused this randomness and not any pecularity of the site configuration.

Sigma azimuth at the median showed a considerable increase from that measured 20' above the road edge. In the mean values given in Table C-123, this increase approached 100 percent for most hours. At least a portion of this increase was caused by nearby traffic. This is a reiteration of the same traffic induced pattern found at the Grand Central Parkway and at Bruckner Expressway. The diurnal pattern is also more evident in the mean values from this sensor, with the minimum occurring between 0400 and 0500 and the maximum during the evening rush hour. The range was 16.1° or 3 times the range at the higher vane.

The prevailing elevation recorded by vane 2 was -5°. As in the case of vane 1, very large negative values occur on days with precipitation and light winds such as 0300 and 0400 on May 26.

Sigma elevation computed from the elevation angle fluctuations of the median vane averages 9.9° for all hours of monitoring. This is 2.8° or 39 percent higher than that determined from the vane along the road shoulder. The 39 percent sigma elevation increase compares with a 113 percent sigma azimuth increase. The sigma azimuth parameter also increased to a greater degree than sigma elevation at the Grand Central Parkway site. The increases from the farther to the closer (to traffic) vane at Bruckner were of the same order. Sigma azimuth experiences a greater contribution from moving traffic than does a sigma elevation when the measurement is made on a medial barrier with opposing traffic on the sides. The opposing traffic lanes generate a high degree of small scale turbulence between them resulting in highly variable azimuth angles. The effect is mainly in the horizontal and tends to increase the sigma azimuth parameter considerably more than sigma elevation.

Mean wind speeds for the median sensor are plotted in Figure C-101. This curve shows a minimum occurring between 0300 and 0400 and a maximum between 1600 and 1700. The wind speeds were generally higher at the 20' vane than at the 14' vane. The difference in the averages is .4 mph. This decrease of wind velocity from the reference vane to the roadway vane was also seen at Bruckner Expressway and Grand Central Parkway sites. Any additional wind velocity generated by passing traffic is too small to compensate for the difference in wind velocities caused by the elevation difference of the two sensors.

4.10.1 Canal Street between Church and Mercer Streets

4.10.1.1 Site Description

Canal Street, in Lower Manhattan, along with its adjacent buildings, forms the typical city street site. This street carries a large volume of traffic, especially trucks, to and from the Holland Tunnel. During the rush hours, traffic tie-ups are a common occurrence. Figure 4.10-1 shows the two way traffic passing the probing plane at this site.

28,000 vehicles transverse Canal Street daily. Approximately 13,000 vehicles move eastbound while about 15,000 vehicles travel westbound. The average daily traffic speed is 16 mph; however, in high traffic average speed drops to between 5 to 7 mph. The average peak hourly traffic volumes in both directions occur during the morning rush hour.

4.10.1.2 Instrumentation Arrangement

The GE Air Pollution Trailer and the New York State Traffic Trailer were parked parallel, at curbside, on opposite sides of Canal Street. A probe plane to monitor CO emissions of passing vehicles was established between the trailers, as shown in Figure 4.10-2 and 4.10-3.

Thirteen probes were used to monitor CO concentration in the probe plane. Four of these were positioned 20' above Canal Street, one over each traffic direction and one at the edge of the sidewalk at each side. One probe was located outside each trailer, 3' above the street. Outside one building on the south side were positioned four probes at 8', 27', 42' and 80' levels. On the north side, a similar building was equipped with 5', 25', and 50' level probes.

One probe was placed inside the building adjacent to the N. Y. State trailer on the north side at the second floor level.

Two vector vanes were again used to determine the meteorological characteristics for this configuration. Vane 1 was located approximately 5 feet above roof level on the north side of Canal Street. This sensor was on a mast attached to the building fire escape and, as such, was slightly out over the sidewalk. Vane 2 was located on the southwest corner of the trailer parked on the north curb of Canal Street. Both vanes were within a few feet of the probe plane.

A Tape Sampler and a Hi Volume Air Sampler were placed on the roof of the GE trailer.

Measured hydrocarbon concentrations were average site values (average of all probes, including probes 1A and 1B at the GE trailer).

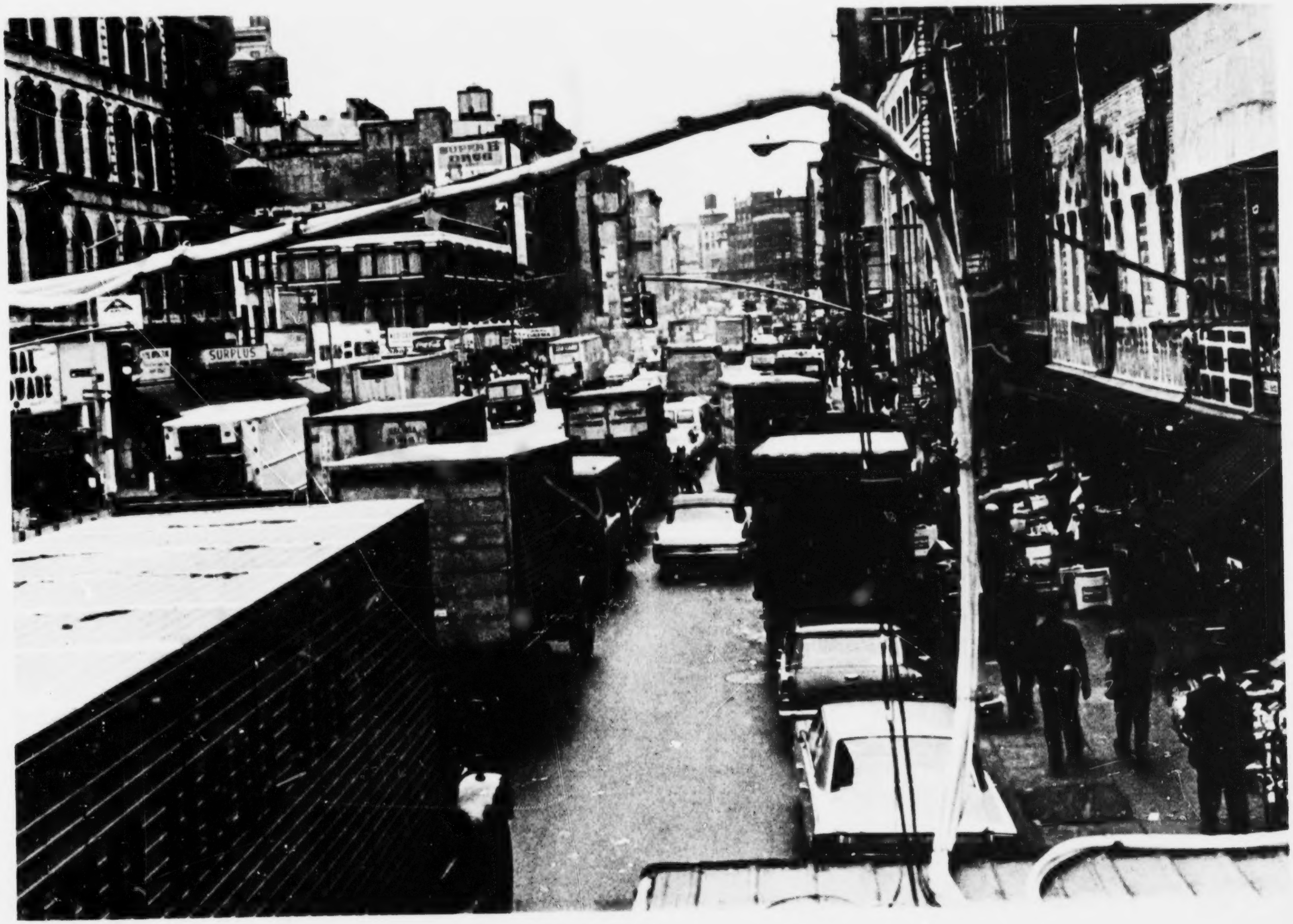
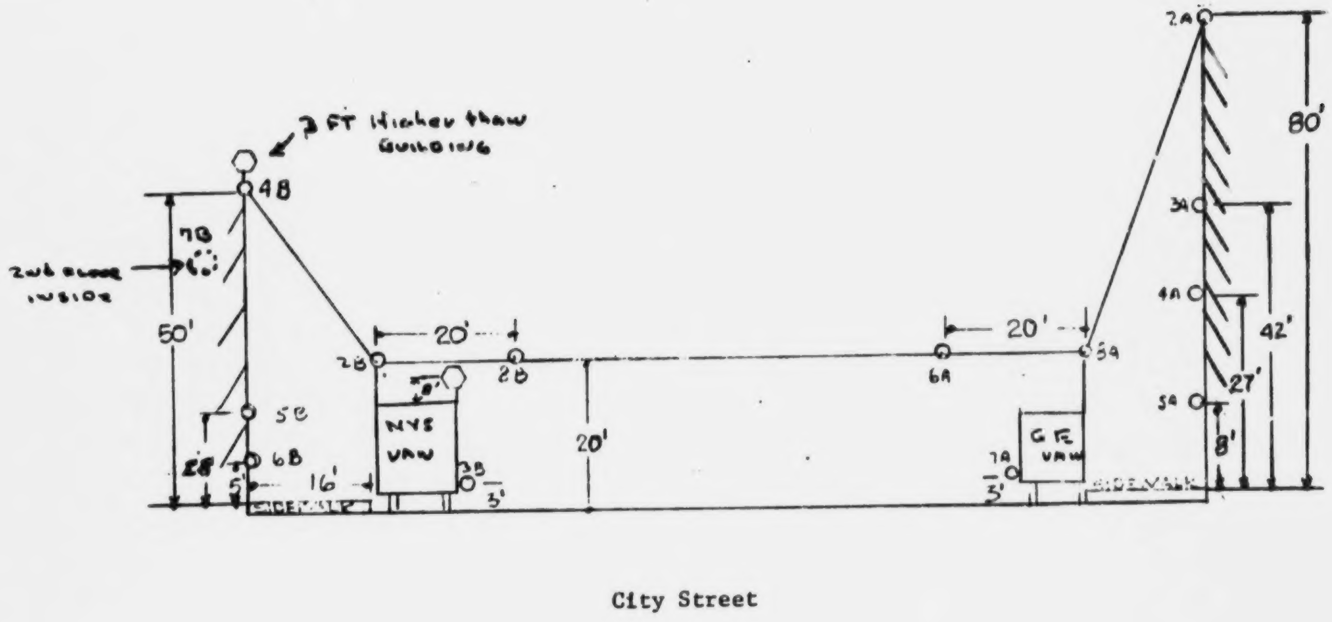

SUPER B DRUG
SURPLUS

Fig. 4.10-1 Canal Street Between Church and Mercer Streets



3 FT Higher than building
4B
7B
2nd floor inside
50'
5B
6B
5'
16'
SIDEWALK
2B
20'
2B
NYS VAN
3B
3'
20'
City Street
20'
6A
5A
GE VAN
7A
3'
SIDEWALK
2A
3A
4A
5A
80'
42'
27'
8'

Fig. 4.10-2 Canal Street between Church and Mercer - Elevation View

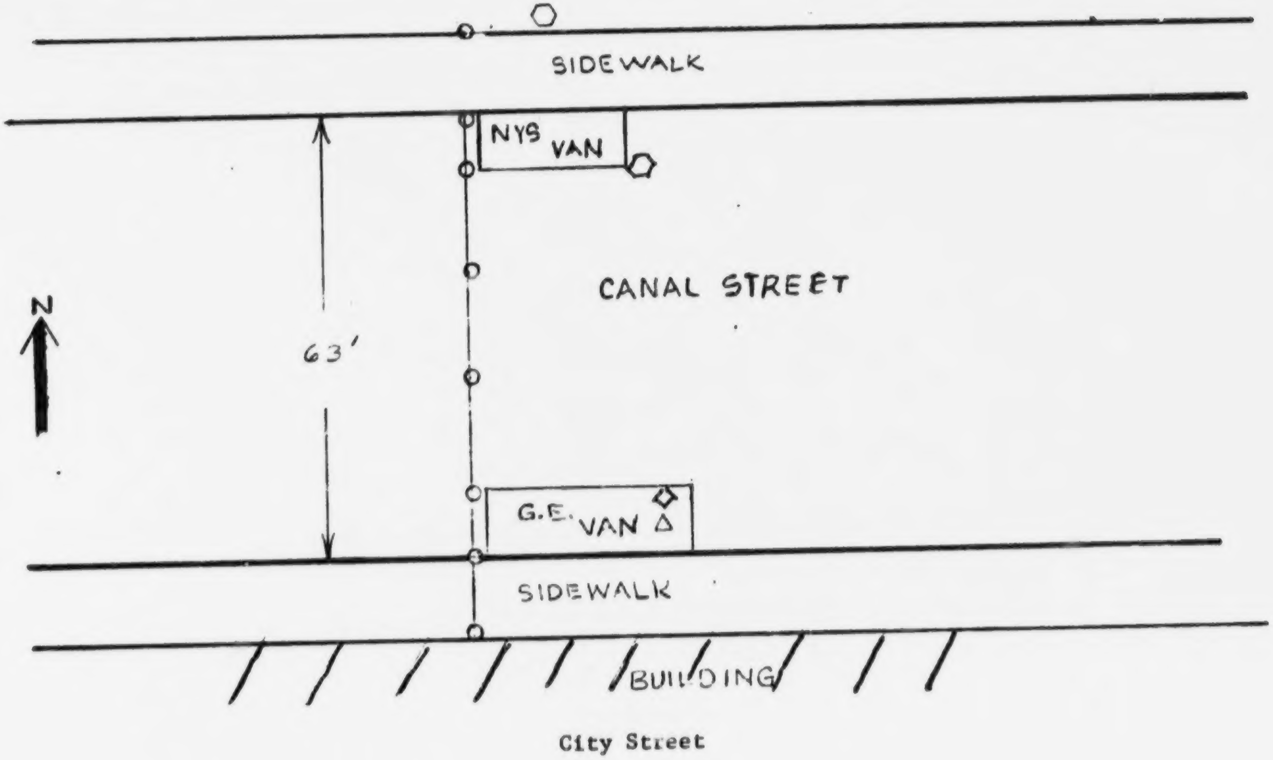

SIDEWALK
NYS VAN
CANAL STREET
N
63'
G.E. VAN
SIDEWALK
BUILDING
City Street

Figure 4.10-3 Canal Street between Church and Mercer Streets - Plan View

4.10.1.3 Meteorological Conditions

The monitoring performed at this site was divided into two periods: June 10 to June 15, and June 23 through July 2. Weather conditions before and after the interruption in monitoring were essentially the same. These conditions were generally characterized by low wind velocities and low turbulence.

The frequency distribution of the azimuth angle at the roof level (Figure C-105) shows two peaks similar to the distribution recorded at the deep and shallow cut sites. The two peaks are near 175° and 15°, or easterly and westerly winds, respectively. (0° at this site is a wind exactly parallel to the road and blowing from the west.)

Sigma azimuth averaged for all hours at the roof location was 10.8°, one of the lowest averages of any site. The plot of hourly mean sigma azimuth shows this turbulence parameter to be virtually constant over the average 24 hour day. The range is only 4.7°.

Wind elevation angles recorded at the roof level were generally negative indicating descending air. The prevailing elevation direction was -15°.

Sigma elevation at roof level was virtually constant over the average 24 hour day as shown in Figure C-108. The minimum occurs near 0500 and the maximum near 1400. The average of 6.8° is lower than any other site with the exception of 54th and Sutton Place. This is a reflection of the settled, summer type weather which predominated at this site.

The mean wind speed of 2.9 mph was also among the lowest of any site. The diurnal wind speed pattern shows a minimum near 0600 and a maximum near 1500.

A bimodal distribution is again evident in the frequency of occurrence histogram (Figure C-113) for the vane located on the trailer parked at curbside on the north side of Canal Street. The peaks are at 5° and 165° which indicates a counterclockwise displacement of about 10° from the sensor at roof level. This displacement may not be real however, since 10° is within the estimated error involved in orienting the sensor.

Sigma azimuth was higher at the roof level than in the street but only by about 1.2°. The diurnal pattern for the vane in the street is also flat with a weak maximum occurring at 1700. There was apparently only a negligible contribution to sigma azimuth by passing vehicles because the turbulence parameter curve is unlike the traffic curve and the values of sigma azimuth decreased from the roof to the road. It is likely that traffic velocity at this site was so slow that any turbulence generated by passing vehicles was too small to be detected.

The same discussion may be applied to the sigma elevation turbulence parameter. Although this quantity does increase from roof to road, the increase is so small (.4^{o}) as to be insignificant. In addition, the diurnal curve is so flat that the minimum and maximum are practically unrecognizable. Although traffic patterns are different than at any other site, there is still at least one pronounced maximum in the morning. This maximum is not reflected in the sigma elevation curve of the wind sensor closest to the traffic.

Wind speed in the street averaged 2.7 mph over all monitoring hours. This is .2 mph less than at the roof level. The wind speed curve has essentially the same shape as the curve for the roof level vane.

Canal Street may be considered an open cut from a meteorological standpoint since the azimuth angle is restricted to a bimodal distribution. The normal increase in turbulence expected from moving traffic, however, is missing -- probably due to low vehicular velocities.

4.11.1 Trans Manhattan Expressway at George Washington Bridge Plaza

4.11.1.1 Site Description

George Washington Bridge Plaza is formed by four hi-rise apartment buildings built directly over the Trans Manhattan Expressway in upper Manhattan. The expressway is the main traffic artery which connects upper Manhattan and the Bronx with New Jersey. The two apartment building complex between St. Nicholas Ave. and Wadsworth Ave. on 179th Street was the structure directly involved in this study. Beneath the buildings were twelve (12) lanes of two-way traffic. A large vent area open to the roadway was located between the buildings. This vent area was 100' long and 180' wide. The vertical distance from the roadway up to the street level (179th St.) was ∼ 45'. The test site is shown in Fig. 4.11-1.

The Trans Manhattan Expressway carries 175,000 vehicles per weekday. Two parallel city streets carry an additional 15,000 vehicles each weekday. Approximately 87,500 travel the expressway each way at an average speed of 38 mph. The eastbound average hourly peak of 6,250 vehicles occurs during the morning rush hour. The westbound peak during the evening rush hours reaches 6,140 vehicles.

4.11.1.2 Instrumentation Arrangement

The GE Air Pollution Van was parked on West 179th Street, approximately 12' from the north edge of the Trans Manhattan Expressway.

16 probes were used to monitor the CO concentrations of the roadway and to obtain indoor-outdoor CO data. Initially, five sets of three probes each were positioned as shown in Figs. 4.11-2 and 4.11-3. These probes were 3', 29' and 50' above the roadway. Two of these probes (5A & 5B) were relocated on July 21 to an apartment building adjacent to the vent area. One probe was installed inside a 3rd floor apartment ∼ 60' above the top of the expressway and the other outside the same apartment. On July 27, these probes were moved to a 9th floor apartment ∼ 100' above the expressway. These indoor-outdoor probe locations were 32' east of the main probing plane and over the north-most lane of the expressway. The sixteenth probe was placed 50' west of the other probes along the north wall, 29' above the roadway.

One vector vane system was in operation at the George Washington Bridge site. This vane was designated number four and is shown as such in Appendix C. The vector vane sensor was located beneath the apartment structure and approximately 15' east of the end of the "tunnel" formed by the roadway passing under the building. It was located on the divider separating the six eastbound lanes into two groups of three and was 14' above the road surface.

Hi vol samples were taken from the trailer roof and the outside balcony of an apt. (23rd floor) in the adjacent building.

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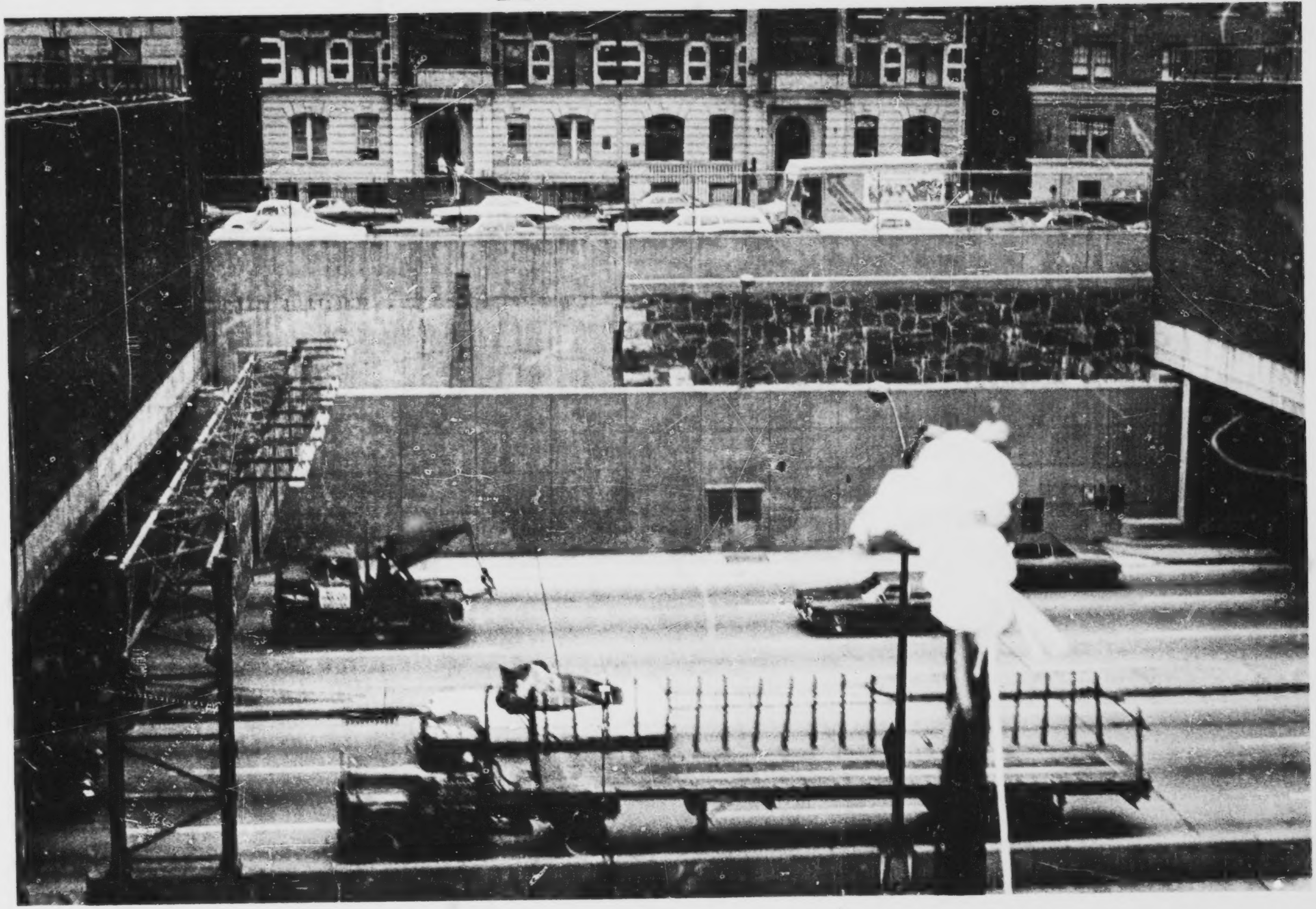


Fig. 4.11-1 Trans-Manhattan Expressway at George Washington Bridge Plaza

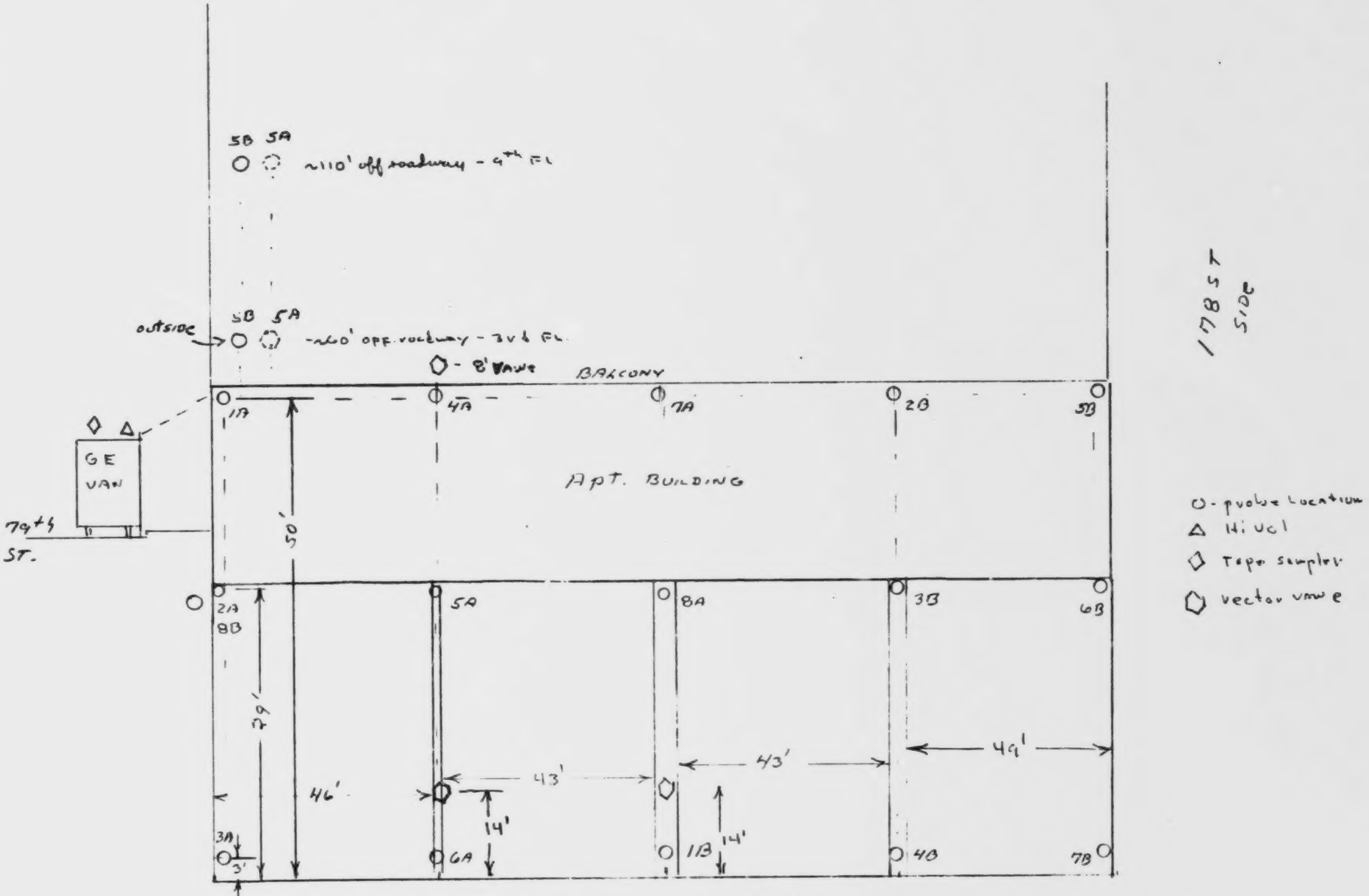

5B 5A
~110' off roadway - 4th FL
OUTSIDE
5B 5A
~60' off roadway - 3rd FL
- 8' vane
BALCONY
1A
4A
7A
2B
5B
GE
VAN
179th
ST.
APT. BUILDING
50'
2A
8B
5A
8A
3B
6B
29'
46'
43'
43'
49'
14'
14'
3A
3'
6A
1B
4B
7B
178 ST
SIDE
○ - probe Location
△ Hi Vol
◇ Tape sampler
⬠ vector vane
Intermittently Covered Roadway

Fig. 4.11-2 Trans-Manhattan Expressway at George Washington Bridge Plaza - Elevation View

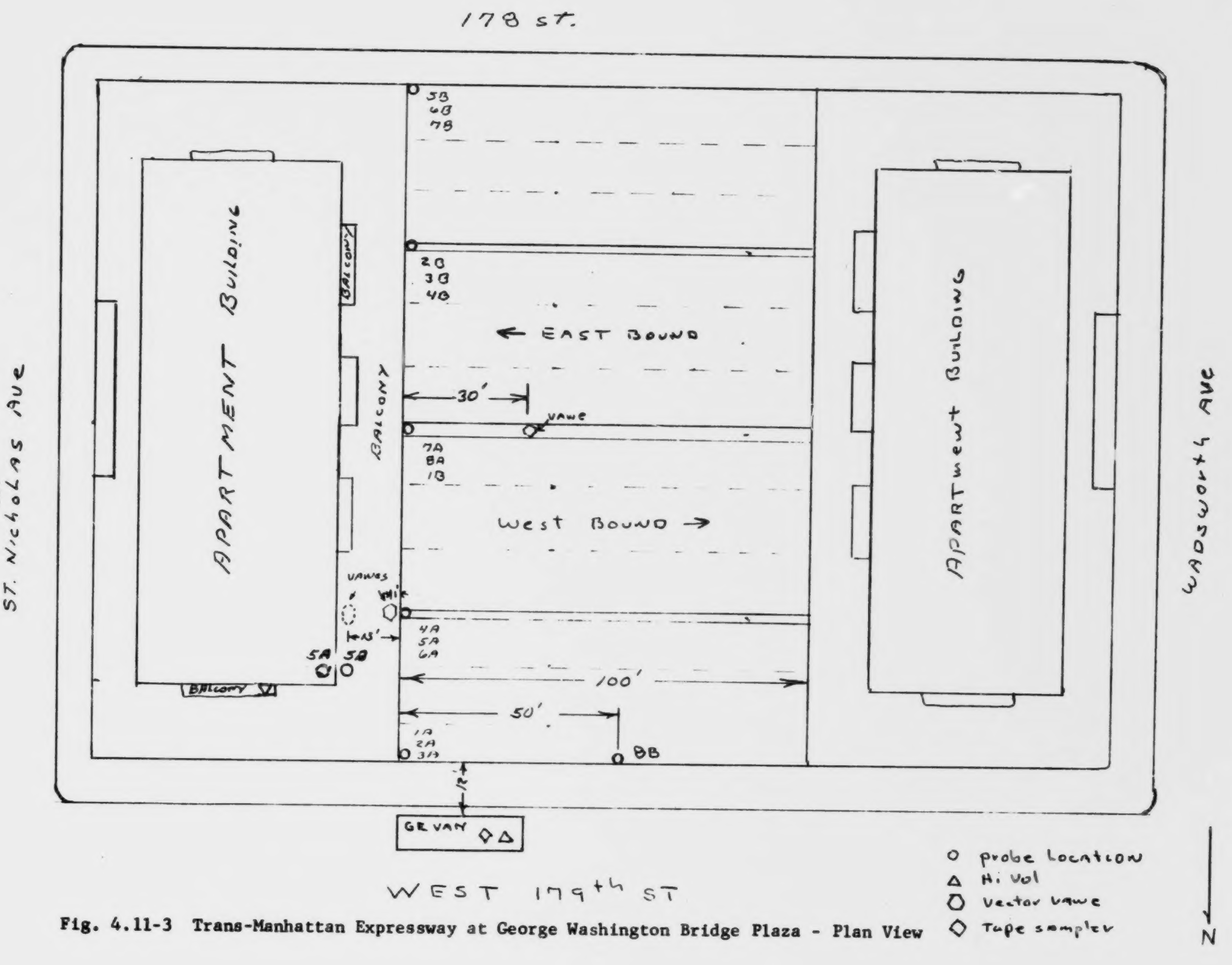

178 st.
APARTMENT Building
Balcony
Balcony
Balcony
APARTment Building
5B
6B
7B
2B
3B
4B
EAST BOUND ←
30'
vawe
7A
8A
1B
West Bound →
vawes
15'
5A
5B
4A
5A
6A
100'
50'
1A
2A
3A
8B
2'
GE VAN
ST. Nicholas Ave
Wadsworth Ave
WEST 179th ST
○ probe Location
△ Hi Vol
⬡ Vector vawe
◇ Tape sampler
N

Fig. 4.11-3 Trans-Manhattan Expressway at George Washington Bridge Plaza - Plan View

A tape sampler sampled the air adjacent to the trailer. A hydrocarbon analyzer, inside the trailer, sampled all probes and recorded an average concentration for the site.

4.11.1.3 Meteorological Conditions

The meteorological monitoring period at this site encompassed the days between July 16 and August 5. General meteorological conditions were again quite calm in comparison with earlier sites. No usable azimuth data was obtained due to a malfunction in the transmitter electronics. The missing azimuth data, of course, precludes any sigma azimuth data.

Elevation angle data was available for most of the period. The elevation frequency of occurrence histogram shows over 98.5% of all recorded data was in the range of $0^o - 10^o$. This is as would be expected since any wholesale vertical movement is effectively prevented by the roof over the road.

Sigma elevation is very constant over the average 24 hour day with a range of only 1.6^o. At first, this may seem surprising considering the experience at the partially covered Grand Central Parkway site. The explanation is that the sensor at this site was placed between two streams of traffic moving in the same direction while at the cantilever site, the sensor was between opposing traffic lanes.

5.0 HIGHWAY PLANNING FACTORS

The purpose of this section is to apply the Superposition model directly to a hypothetical roadway in order to ascertain whether the roadway will produce carbon monoxide levels at the receptor locations that are in excess of the National Air Quality Standards.

Problem #1

Given: A four lane highway (Figure 5-1) carrying traffic volumes of 3000 vehicles/hr. at an average speed of 30 miles/hr. in one direction and 4200 vehicles/hr. at an average speed of 10 mph traveling in the other direction. The proposed highway is to be located such that the nearest receptor will be 75 ft. from the roadway.

Solution: Equation 3.3-6 is employed to determine ϕ for each side of the highway.

$$\phi_i = [-.54\ (T\ ) + 29.6] \times 10^{-3}$$

$$\phi_1 = [-.54 \times 30 \text{ mph} + 29.6] \times 10^{-3} = 13.4 \times 10^{-3}\ \frac{\text{ppm-hr.}}{\text{veh.}}$$

$$\phi_2 = [-.54 \times 10 \text{ mph} + 29.6] \times 10^{-3} = 24.2 \times 10^{-3}\ \frac{\text{ppm-hr.}}{\text{veh.}}$$

Equation 3.3-7 is employed to determine the CO concentration at receptor locations 1 and 2. The concentration at receptor 1 is computed as follows:

$$[\text{CO}]_{R1} = \sum_{i=1}^{2} \phi_i\, N_i \exp\, [-a\, \rho_{iR}]$$

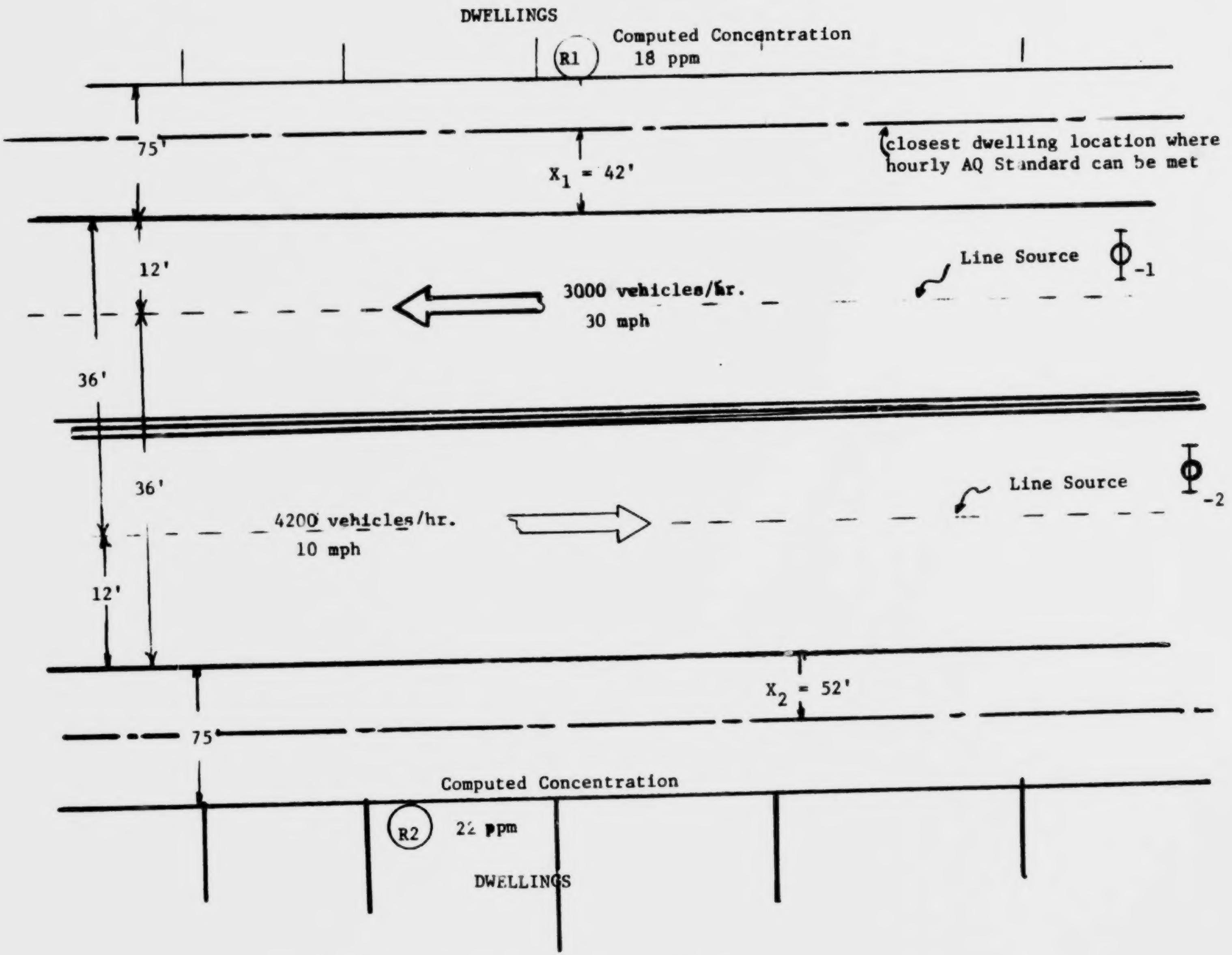
$$= (13.4 \times 10^{-3}\ \frac{\text{ppm-hr.}}{\text{veh.}}\ .\ 3000\ \frac{\text{veh.}}{\text{hr.}})\ .\ \exp\, [-.02\ \text{ft.}^{-1}\ .\ 87\ \text{ft.}] +$$

$$(24.2 \times 10^{-3}\ \frac{\text{ppm-hr.}}{\text{veh.}}\ .\ 4200\ \frac{\text{veh.}}{\text{hr.}})\ .\ \exp\, [-.02\ \text{ft.}^{-1}\ .\ 111\ \text{ft.}]$$

$$= [40.2\ .\ \exp\ (-1.74) + 101.6\ .\ \exp\ (-2.22)]\ \text{ppm}$$

$$= [40.2\ (.175) + 101.6\ (.108)]\ \text{ppm}$$

$$= (7.0 + 11.0) = 18\ \text{ppm}$$


DWELLINGS
R1
Computed Concentration
18 ppm
75'
$X_1 = 42'$
closest dwelling location where
hourly AQ Standard can be met
12'
Line Source
Φ_{-1}
3000 vehicles/hr.
30 mph
36'
36'
Line Source
Φ_{-2}
4200 vehicles/hr.
10 mph
12'
$X_2 = 52'$
75'
Computed Concentration
R2
22 ppm
DWELLINGS

Proposed Highway to be evaluated for Air Quality

Figure 5-1

The concentration at receptor 2 is computed as follows:

$$[\text{CO}]_{R2} = (24.2 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 4200 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot 87 \text{ ft.}] +$$

$$(13.4 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 3000 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot 111 \text{ ft.}]$$

$$= 101.6 \exp (-1.74) + 40.2 \exp (-2.22)] \text{ ppm}$$

$$= [101.6 (0.175) + 40.2 (.108)] \text{ ppm}$$

$$= (17.8 + 4.3) = 22.1 \text{ ppm}$$

Therefore, it is seen that if this traffic volume and speed persists for a minimum 4 hours and then drops to zero, the National Air Quality Standards would be exceeded.

Problem #2

At what distance from each side of the highway described in Problem #1 will the CO concentration equal 35 ppm-max. 1 hr.

Solution: Equation 3.3-7 is employed, by trial and error to determine the distance from the edge of roadway at which the concentration at the receptors, R_1 and R_2, will equal 35 ppm.

$$[35]_{R1} = (13.4 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 3000 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot (12 + X_1)] +$$

$$(24.2 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 4200 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot (36 + X_1)]$$

$$[35]_{R2} = (24.2 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 4200 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot (12 + X_2)] +$$

$$(13.4 \text{ X } 10^{-3} \frac{\text{ppm-hr.}}{\text{veh.}} \cdot 3000 \frac{\text{veh.}}{\text{hr.}}) \cdot \exp [-.02 \text{ ft.}^{-1} \cdot (36 + X\ )]$$

It is found that $X_1 = 42$ ft.

and $X_2 = 52$ ft.

Problem #3

It is proposed that a 6 lane highway, 100 feet wide, with a cantilever cover over the outside lanes be constructed. The cover will be 10 ft. above road level at each edge. It is estimated that peak traffic volume will be 8500 cars/hr. (no truck traffic permitted). The rush hour traffic peak will be 6000 cars/hr. inbound in the morning and outbound in the afternoon. What CO concentration can be expected on the roadway?

Solution: Using Figure 2.2-7, the CO concentration at the 3 ft. level on the median strip for 8500 vehicles/hr. is found to be 28.5 ppm. At the 10 ft. level, for 8500 vehicles/hr. the CO concentration is 20 ppm.

The horizontal concentration profile in Figure 2.1-13B is used to extrapolate from the middle of the road to the edge of the road. From Figure 2.1-8B, it can be seen that the two-way traffic shown during the 7 - 8 AM period approximates the anticipated AM rush-hour condition. Therefore, assuming the westbound lanes are inbound, a line from 20 ppm at y = 50 feet with a slope which is halfway between that shown for the 6 - 7 AM and 8 - 9 AM curves, indicates approximately 32 ppm at 100 feet. Similarly, a 22 ppm concentration is expected at the edge of the outbound lanes.

Problem #4

It is expected that southbound traffic on the F.D.R. Drive will increase by 500 vehicles/hr. and northbound traffic will increase by 300 vehicles/hr. What will be the anticipated CO concentration along the west wall at rush-hour periods?

Solution: Using Figure 2.1-8A, it is seen that the morning traffic peak occurs between 8 - 9 AM and the afternoon between 4 - 5 PM. The morning traffic consists of 3300 vehicles southbound and 2700 vehicles northbound, or a total of 6000 vehicles. The anticipated morning peak, due to increased two-way traffic, is 6800 vehicles. Using the $z = 3'$ curve of Figure 2.2-1, it is seen that 83 ppm CO can be expected for a two-way traffic flow of 6800 vehicles.

By a similar process, the anticipated afternoon peak of 7600 vehicles will produce approximately 99 ppm CO. (Note that it is necessary to project the $z = 3'$ curve)

Problem #5

Determine the anticipated CO concentration at the edge of the westbound lane of the Viaduct road at noontime.

Solution: From Figure 2.1-9B, it can be determined that the total traffic is approximately 4600 vehicles/hr. Using Figure 2.2-8, it is found that the CO concentration on the median strip at the 10 foot level is approximately 10.2 ppm. Using the horizontal profile curve of Figure 2.1-4A, it is found that the concentration decays from 10.2 ppm in mid road at the 10 foot level, to about 6.8 at the edge of the westbound lane. The vertical profile shows a decay from 6.8 at the 10 foot level to about 6.0 ppm at the 0 foot level.